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ELECTROLUMINESCENCE: AN ANNOTATED BIBLIOGRAPHY

SPECIAL BIBLIOGRAPHY
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Compiled by

PETER R. STROMER

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Lockheed

MISSILES & SPACE COMPANY

A GROUP DIVISION OF LOCKHEED AIRCRAFT CORPORATION

SUNNYVALE, CALIFORNIA

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ABSTRACT

The recent literature of carrier injection (D. C.) and intrinsic (A. C.) electroluminescence has been reviewed. Electroluminescence is defined as the excitation of a phosphor by an electric field whereby the electrical energy is converted to visible radiation. Other forms of energy such as photons, cathode rays, x-rays, etc. give rise to photoluminescence, cathodoluminescence, and x-ray luminescence, respectively. References to these other forms of luminescence have been included only in those instances where they have been studied in combination with electroluminescence.

Entries are arranged alphabetically by senior personal author. Both a source and subject index are supplied to provide different approaches to the use of this material.

INTRODUCTION

A review has been made of recent literature on Electroluminescence. Both types of electroluminescence, carrier injection (provided by direct current) and intrinsic (alternating current) are included.

Electroluminescence may be defined as the excitation of a phosphor by an electric field whereby the electrical energy is converted into visible radiation. Other forms of energy, photons, cathode rays, x-rays, etc. may also be applied to a luminescent phosphor, giving rise to photoluminescence, cathodoluminescence, and x-ray-luminescence, respectively. References to these other forms of luminescence have been included only in those instances where they have been studied in combination with electroluminescence. While no single theory has conclusively explained the mechanism of electroluminescence (EL) to date, much activity has been devoted to EL applications. Used separately or in conjunction with photoconductive and/or ferroelectric materials, new light sources, display panels, readouts, computer memory and switching devices, and flat screen television have been proposed.

Entries in the bibliography are arranged alphabetically by senior personal author. Both a source and subject index are provided, offering different approaches for the use of this material. The facilities of the Lockheed Missiles and Space Company Technical Information Center were utilized in the bibliographic preparation.

Search was completed December 1962.

TABLE OF CONTENTS

1. Adams, I. and J. W. Mellichamp
Electrofluorescence of rare-earth-activated Al_2O_3. J. CHEM. PHYS. 36: 2456-9, 1 May 1962.

α - Al_2O_3 was activated with Sm^{2+}, Sm^{3+}, Eu^{3+}, Gd^{3+}, Tb^{3+} and Dy^{3+} by mixing powders of the rare-earth oxide with γ - Al_2O_3 and firing in an N_2 and then in a Cl_2 atmosphere at 800°-1000° C. When these activated powders are placed between a metal base plate and a conducting glass plate and about 500 V d. c. is applied, electrofluorescence is observed. The emitted spectra are characteristic of the fluorescence is observed. The emitted spectra are characteristic of the fluorescence of the rare-earth ion in the corundum structure. A mechanism for excitation is discussed.

2. Adams, I., T. R. AuCoin and J. W. Mellinchamp
Electrofluorescence of ruby powder. J. APPL. PHYS. 33: 245, Jan 1962.

The preparation of electroluminescent (or electrofluorescent) ruby powder is described. Al_2O_3 is mixed with 0.05 to 2 mole per cent Cr or a rare earth element and is fired in N_2 and Cl_2 gases at 500° to 1000° C. The room temperature spectrum emitted from the electrofluorescent ruby powder is compared with that from a fluorescent ruby crystal excited with a 366 mμ mercury uv lamp. When Tb is used, the emitted spectra show structure similar to that of the fluorescence of a $NaTb(WO_4)_2$ crystal excited with uv. Except for Cr-doped Al_2O_3, most of the doped samples displayed little or no fluorescence when stimulated with a mercury uv lamp. The mechanism which gives rise to electroluminescence in Al_2O_3 is discussed.

3. Adams, I., T. R. AuCoin and G. A. Wolff
Luminescence in the system Al_2O_3-AlN. J. ELECTROCHEM. SOC. 109: 1050-1054, Nov 1962.

Aluminum nitride and aluminum oxide are mutually soluble at high temperatures. A number of solid solutions and reaction products of various compositions in the system AlN-Al_2O_3 have been prepared at about 2000° C, which can be described by one general formula

$$Al_{(2+x/3)}O_{(3-x)}N_x$$

where x represents the number of nitrogen atoms.

Five phases were observed: (i) Al_2O_3 of corundum structure with negligible solubility of AlN; (ii) a phase similar to δ-alumina found when the AlN content was about 5.5 mole %; (iii) a spinel phase with an AlN content up to 50 mole %; (iv) a phase obtained when the AlN content was between 50 and 67 mole % (this phase always occurred mixed with phase iii); (v) AlN of wurtzite structure with up to about 17 mole % Al_2O_3.

Phases (ii) to (v) show no observable fluorescence but broad band phosphorescence in the blue when excited with 2537Å radiation. Manganese activation produces a green or a red luminescence which is attributed to transitions of Mn^{2+} and Mn^{4+} at different lattice sites. Electroluminescence in the visible is observed in all phases when suitably activated.

4. Alfrey, G. F. and C. S. Wiggins
Electroluminescence at grain boundaries in gallium phosphide. In SOLID STATE PHYS. IN ELECTRONICS AND TELECOMMUN. N. Y., Academic Press, 1960. v. 2, p. 747–750.

The electroluminescence of GaP is discussed. A few volts of direct current applied to the crystal is sufficient to produce some electroluminescence. For greater luminescent intensity, pulsing techniques are used to avoid overheating the crystal, since its impedance falls rapidly with increasing current. The electroluminescence is shown to occur at grain boundaries. As the current grows, the electroluminescence tends to grow throughout the boundary inside the crystal. Not all boundaries are electroluminescent, and almost all voltage drops occur at grain boundaries. The impedance across a grain boundary is nonlinear. The use of a scanning electron microscope technique to investigate voltage barriers at a grain boundary is described. Segration of donor impurities at grain boundaries is discussed.

5. Alfrey, G. F., I. Coole and K. N. R. Taylor
Some experiments on zinc sulphide crystals.
In SOLID STATE PHYS. IN ELECTRONICS AND TELECOMMUN. N. Y., Academic Press, 1960. v. 2, p. 816–818.

Several experiments on the electroluminescence of crystals are described. Electroluminescence in ZnS is related to the barrier field and the bulk properties of the crystal. The process which causes reduction in the height of scintillation pulses in ZnS crystals with an applied field is discussed. Differences between ac and dc electroluminescence are considered. A theory to account for the variety of electroluminescent light waveforms and for the variation of electroluminescence with frequency is presented.

6. Andreev, I. S., G. B. Arzumanyan and L. V. Zȳrina
Regarding the possibilities of stimulating the electroluminescence properties of crystals.
BULL. ACAD. SCI. USSR, PHYS. SER.
25:516-18, 1961. (Tr. from Russian)

A description of the effects of phosphor preparation details on the emission spectrum, frequency dependence and brightness of electroluminescence in ZnS. Observations were made on the brightness waves with sinusoidal or square-wave excitation. Electrolysis of ZnS powder at 700° -1000° C may be used to introduce activators and to induce electroluminescence.

7. Andrianov, A. S. and M. L. Kats
Electro-x-ray luminescence of KBr crystals.
OPTICS AND SPECTROSC. 11:228-9, Sep 1961.
(Tr. from Russian)

This luminescence occurs under simultaneous action of X-rays and an electric field. An intensity amplification for luminescence up to a factor two was observed for fields near the breakdown value. From the fact that Sn-activated KBr phosphors showed no enhanced amplification factor over the pure crystals, it is concluded that the action of the field is to make electrons or holes from traps or from the valence band mobile, and that their recombination results in luminescence.

8. Antonov-Romanovskij, V. V.
On the electroluminescence of powdered zinc sulphide layers. CZECH. J. PHYS. 9:146-60, 1959.

Voltage dependence of electroluminescence in very thin binderless layers confirms the impact ionization theory of the mechanism. Comparison of photo and electroluminescence of ZnS:Cu containing Nd or Eu allows an estimation of the volume of the crystal in which the light output occurs. Transfer of excitation from the region of field concentration to the whole volume is shown by the relation between electroluminescence in ZnS:Cu, Al and the stored light sum. The same conclusions arise from studies of relaxation processes which control the proportions of constant and variable electroluminescence.

9. Armed Services Technical Information Agency
ELECTROLUMINESCENCE. AN ASTIA REPORT BIBLIOGRAPHY. Rept. no. ARB 13,344. 1962. (240 refs.)

Report bibliography covering the ASTIA document collection of reports from 1958–1962.

9A. Aven, Manuel
ELECTROLUMINESCENT ZINC SULFIDE PHOSPHORS. (Assigned to General Electric Co.) U. S. Patent 3,000,834. Application 18 Apr 1958.

A decrease in the surface: volume ratio of ZnS-based green-emitting electroluminescent phosphors results in an increase in resistance to deterioration of spectral properties by atm. H_2O. The larger sized phosphor particles are prepared by prefiring a mixture of precipitated ZnS and ZnO (10–40% by wt.) at 1150–250° for 1 hour, cooling, and adding 0.1-0.75 mole % Cu and 1-3 mole % Cl (as NH_4Cl or $ZnCl_2$); this composite is then refired at 850-950°. All firings are performed with exclusion of air.

10. Ballentyne, D. W. G.
Crystal structure and electroluminescence in ZnS. J. PHYS. CHEM. SOLIDS 10:242, Jul 1959.

Electroluminescence appears in ZnS when the Cu content increases to 10^{-3} parts by weight. This coincides with the disappearance of deep traps and the change from hexagonal to cubic structure. Ag replacing Cu produces the same effects above a concentration of 10^{-2}.

11. Ballentyne, D. W. G.
Electroluminescence. CONTEMP. PHYS. 3:112–124, Dec 1961.

The phenomenon of ac electroluminescence is reviewed. The review touches on the preparation and properties of electroluminescent phosphors; the temperature, voltage, and frequency dependences of electroluminescence brightness; theories of electroluminescence; and applications of electroluminescence. A classified bibliography is included.

12. Ballentyne, D. W. G.
Electroluminescence - a disorder phenomenon.
J. ELECTROCHEM. SOC. 107:807-10, Oct 1960.

In general, electroluminescence is considered to occur at a junction between a semiconducting crystal and a metal or electron rich material. The present work indicates that electroluminescence only occurs in zinc sulphide powders containing both sphalerite and wurtzite. This suggests that electroluminescence is a disorder phenomenon associated with stacking faults in the crystal.

13. Ballentyne, D. W. G. and B. Ray
Electroluminescence and crystal structure in the alloys system ZnS-CdS. PHYSICA (NETHERLANDS) 27:337-41, Mar 1961.

Alloys were annealed to obtain equilibrium conditions. It was confirmed that solid solution occurs at all compositions and the variation of lattice parameters with concentration has been determined. The effect of adding excess (<1%) Cu has been investigated with special reference to the appearance of electroluminescence in alloys of this type, and to the structure.

14. Ballentyne, D. W. G.
On the behavior of electroluminescent phosphors on irradiation with ultra-violet. J. PHYS. CHEM. SOLIDS 21:131-133, Oct 1961.

The enhancement of electroluminescence in ZnS:Cu, Al phosphors by ultraviolet irradiation is described on the basis of a band model. It is suggested that excess Cu in the phosphor produces a p-type phase of cubic material containing hexagonal material with a low concentration of Cu ions. The wave functions of the perturbed states overlap and an impurity band is formed. The p-type cubic material is in contact with less heavily doped n-type hexagonal material. With proper bias, electrons in luminescent centers in the forbidden gap of the n-type material tunnel into the impurity band. When the bias is reversed, the electrons from the impurity band tunnel into states of the conduction band. The electrons then either directly recombine with the ionized luminescent centers or are trapped in the traps. The trapped electrons are thermally released into the conduction band and recombine with the luminescent centers. The recombination is accompanied by an emission of photons of energy h . The ultraviolet radiation reduces the occupancy of the impurity band. The number of electrons

which can tunnel from the luminescent center is thus increased. As these electrons are transferred to the traps, the brightness of the emitted light is enhanced.

15. Balzek, R. J.
ELECTROLUMINESCENT DEVICE. (Assigned to Westinghouse Electric Corp.) U. S. Patent 3,048,733. 7 Aug 1962. Application 9 Sep 1960. 4p.

Increased light output and efficiency has been achieved with plastic dielectric material composed of 5-35 wt. % of a light-transmitting nitro- or nitrile-substituted, benzene compound (such as 2,4-dinitrophenetole) dissolved in a base material of any conventional plastic dielectric (preferably of poly(vinyl chloride)-type) having a boiling point of at least 200°. Optimum concentration of organic additive is 25% to get 2-fold increase in capacitance and 40% increase in efficiency of the cell.

16. Batailler, G.
The effect of the percentage harmonic of the stimulating wave on the average luminescence from an electroluminescent cell. C. R. ACAD. SCI. (FRANCE) 255:94–6, 2 Jul 1962. (In French)

The relationship between the simulating electrical voltage V_{eff} and the resultant luminescence L is developed for a complex voltage formed by the superposition of two waveforms of different frequency, one being a harmonic of the other. Measurements show that for a harmonic of given constant percentage, the relationship between log. L and $1/NV_{eff}$ is linear, the position and slope of the straight line being dependent upon the percentage harmonic content and the order of the harmonic. The corresponding relationship was found to be non-linear when the percentage harmonic content was varied. Below a certain limiting voltage, the addition of a given percentage harmonic increased the luminescence above the value obtained for the pure fundamental wave with the same effective voltage. Above this limiting voltage the reverse effect occurred and the luminescence deficit was found to be larger for the high order harmonics.

17. Batailler, G., P. Bugnet and S. Durand
Experimental study of the spherical brilliance of an electroluminescent cell energized by a non-sinusoidal supply. BULL. SOC. FRANC. ELECT. 3(Ser. 8):261-66, May 1962. (In French)

Investigates the possibility of increased output from ZnS(Cu) cells by energizing them from a supply of several hundred cycles frequency which is rich in harmonics. The output gives two peaks per cycle for sinusoidal waveform and the introduction of harmonics causes a sudden increased emission when the voltage level changes direction. It is shown that the brilliance due to non-sinusoidal supplies is inferior to that obtained without harmonics except for very short time values.

18. Baum, F. J. and F. J. Darnell
Birefringence studies in electroluminescent zinc sulfide. J. ELECTROCHEM. SOC. 109: 165-166, Feb 1962.

Birefringence measurements performed on ZnS crystals to study the layered structure in the crystals and to corrolate the structure with electroluminescence are discussed. The crystals contained both cubic and hexagonal structure. The amount of hexagonal structure in an element of a ZnS crystal can be determined by the degree of birefringence, provided that stacking sequences are regular. By superimposing birefringence and electroluminescence spectra in a spectrograph, it was possible to make a structurally sensitive characterization of the region exhibiting electroluminescence. It was found that electroluminescence occurred only in crystal volumes characterized by varying structure and that there is no relation between the occurrence of electroluminescence and the value of birefringence.

19. Bell, D. C. and R. J. Blazek
MULTICOLOR ELECTROLUMINESCENT LAMP.
Westinghouse Electric Corp. ASTIA AD 247 178

Basic and applied research is reviewed on the development of multilayer multicolor electroluminescent lamps adaptable to the illumination of aircraft instruments and indicators. Both rigid and flexible types were studied. In order to satisfy the objectives of brightness, maintenance of brightness during operation, color and flexibility as well as the environmental tests, considerable improvements were sought in lamp components and in lamp fabrication techniques. Significant advances resulted, including

17. Batailler, G., P. Bugnet and S. Durand
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the development of a new red phosphor. The practicability of multilayer multicolor electroluminescent lamps, both the rigid and flexible types, was demonstrated by the successful fabrication of sample lamps.

20. Bernanose, A.
L 'électroluminescence organique. SOC FRANCAISE DES ELECTRICIENS–BUL 3(30): 299–307, Jun 1962.

Organic electroluminescence; examination of luminescence obtained by subjecting to a-c electric field cellular or other films impregnated with fluorescent organic compound and made insensitive to humidity; preparation of such films; theoretical explanation of electroluminescence.

21. Blanc, J. and R. H. Bube, et al
MAXIMIZING THE PERFORMANCE OF PHOTO_ CONDUCTORS. David Sarnoff Research Center, Princeton, N. J. Scientific Rept. 2. 15 Sep 61–15 Mar 62. 143p. (65 refs.) (Contract AF 19(604)8353) AFCRL 62–158 ASTIA AD-278 050.

A simple analysis of the limitations on photoconductivity performance of a sensitive photoconductor like CdS indicates that ultimate likely success in materials control and development will not yield a material with response time less than 1/10-second for .0001 ft-c illumination or lower. The initial stages of success in preparing larger crystals of CdS with improved photoconductivity performance for low light intensity excitation have been achieved. Large boules of pure CdS and of CdS with controlled impurities, in sizes of 12 mm in diam. and 40 mm long, have been prepared by sublimation or chemical transport with a moving temperature gradient. The reality of trap densities of the order of 10 to the 19th power 1/cc in annealed gallium arsenide crystals was substantiated and evidence presented relating these traps to crystal defects. Apparatus capable of measuring mobilities in material with conductivity as low as 10 to the -10th power ohm/cm over the temperature range from 77 to 450 K was put into operation. Photovoltage measurements on cadmium sulfide crystals were used to obtain basic information about the nature of surface states.

22. Bodi, L. J.
Flow synthesis of gallium phosphide and some properties of gallium phosphide powder layers.
ELECTROCHEM SOC-J 109(6): 497-501, June 1962.

Phosphorus vapor is carried over gallium (III) oxide by stream of hydrogen; oxide undergoes complete conversion to phosphide; thermal treatment enhances average particle size, and electroded GaP powder layers are fabricated; electrical properties and electroluminescence characteristics of these layers.

23. Bodo', Z. and J. Weiszburg
Light patterns of electroluminescent panels.
ACTA PHYS. HUNGAR. 10:241-3, 1959.

Using a photographic technique to integrate the light emitted over a period of time ranging from 8 to 24 hrs, experiments have been performed to identify the position of light emitting regions in electroluminescent ZnS:Cu panels. Every light spot was emitted with both polarities of the applied field, although in some cases there was a great difference in intensity with reversal. The difference is explained by grain orientation and/or by asymmetric properties of the lighting regions themselves.

24. Böer, K. W., H. J. Hänsch and H. Obernik
Electroluminescence of CdS-single crystals.
Part I. Experimental results (in German)
PHYS. STATUS SOLIDI 1(4):352-365, 1961

An investigation of the electroluminescence of CdS single crystals in dc fields is described. Channel- and spot-like green luminescence and strongly localized dots of yellow luminescence have been observed. Photographs of the various types of electroluminescence are presented. The dependence of the electroluminescence on crystal imperfections and on the field distribution, particularly in relation to electro-optical effects are studied. The spectral distribution of the green electroluminescence has also been measured.

25. Böer, K. W. and K. H. Zschauer
The green electroluminescence in CdS single crystals. PHYS. STATUS SOLIDI (In German) 1(2):K36-K37, 1961.

Under a potential of 1000 V applied between evaporated gold electrodes separated by 2 mm, the crystals produce green luminescence at the anode. This light is interrupted by narrow dark bands moving away from the anode towards the cathode. Possible explanations are given.

26. Boiko, L. M.
Effect of radiation on certain characteristics of electroluminescent screens. UKRAIN. FIZ. ZHUR. (In Russian) 6:866-9, 1961.

Electroluminescent screens were investigated with simultaneous electro- and photo-excitation. The frequency dependence had a maximum at 12 to 13 kcps, on the position of which various forms of radiation, ultraviolet, x and gamma radiation, have no effect. The brightness of the luminescent screen in an alternating electric field decreased during irradiation with ultraviolet light and increased during x irradiation, the effect depending on the frequency. The possibility of obtaining "images" on the electroluminescent screen was verified.

27. Bonch-Bruevich, A. M.
Certain regularities in the electroluminescence of ZnS:Cu:Al phosphors with high copper content. OPTICS AND SPECTROSC. (Tr. from Russian) 11(2):114-17, Aug 1961.

A study was made of the kinetics of the decrease in intensity of the green and blue luminescence pulses which accompany the turning on and off of the voltage applied to ZnS:Cu:Al phosphors. A study was also made of the steady state luminescence characteristics (the amplitudes of the luminescence pulses and the light sum emitted under the action of a pulsed voltage). It is shown that essential differences exist between the green and blue luminescence bands with regard to a number of the regularities observed.

28. Bonch-Bruevich, A. M. and V. A. Molchanov
Investigation of electroluminescence pulses emitted by ZnS:Cu,Al phosphors with a high Cu concentration. BULL. ACAD. SCI. USSR, PHYS. SER. (USA) 24(4):477-81, 1961.

Square wave pulses at 100/sec were used to excite ZnS:Cu,Al containing 0.2 g Cu per g ZnS in oil cells, and measurements made on the amplitude of the light pulses, their decay, and the light sum. The green and blue bands have a different emission mechanism, and they also differ in voltage dependence. Microscopic examination of single crystals shows behaviour similar to that of polycrystalline material and not less complicated.

29. Bonch-Bruevich, A. M., Ya. E. Kariss and V. A. Molchanov
Microscopic studies of electroluminescence in ZnS:Cu,Al single crystals. OPTICS AND SPECTROSC. (USA) 11(1):45-7, Jul 1961.

A setup is described for the microscopic study of electroluminescence in single crystals. A synchronous single method with a variable phase shift (sliding phase) was used. It was found possible to investigate the shape, amplitude, etc., of the light pulses emitted by individual crystal regions. Preliminary experiments with ZnS:Cu,Al single crystals indicated the possibility of separating the turn-on and turn-off luminescence; a rule was found to govern the distribution of the ratio of the amplitudes of the turn-on and turn-off luminescence pulses in different parts of the crystal.

30. Bonch-Bruevich, A. M. and O. S. Marenkov
The polarization phenomena in electroluminescent phosphors. OPTIKA I SPEKTROSK., (In Russian) 8(6):855-60, June 1960.

A study of the rapid polarization processes and electroluminescent flashes in the ZnS:Cu:Al phosphor excited with pulses (polarization is used here in the sense of electric charge accumulation or separation). It was found that the electric field due to rapid polarization (there is also long-duration polarization) is established in 10-20 μsec, i.e. during a time interval several orders smaller than the decay time of

electroluminescence. Analysis of the kinetics of electroluminescence decay led to the conclusion that quenching is produced by the polarization field acting in the direction opposite to the external field.

31. Bonfiglioli, G., P. Brovetto, and A. Suardo
CALCULATIONS ABOUT BARRIER-INJECTION ELECTROLUMINESCENCE. National Electrotechnical Inst., Italy. (Technical note no. 7). Jul 1962. 22p. [Contract AF 61(052)-328] . ASTIA AD-284 386.

A calculation is given of the current flowing across a condenser-type electroluminescent cell excited with a constant-slope voltage transient. This is the waveform used in preliminary experiments. The theory followed in this calculation is that advanced by Zalm, whereby tunnel effect at a surface barrier of finite cross extension is invoked. On these grounds, equations are developed which give the shape of the light pulse produced by the EL cell undergoing a linear transient of electrical potential.

32. Bonfiglioli, G., P. Brovetto and C. Cortese
PRELIMINARY EXPERIMENTS ON ELECTRO-LUMINESCENCE OF ZINC SULFIDE. National Electrotechnical Inst., Italy. Rept. on Study of Electron Traps in Dielectrics by Electro-luminescence. (Technical note no. 4). 1962. 15p. [Contract AF 61(052)-328] (AFOSR-1835). ASTIA AD-273 963.

A short review of the literature on electroluminescence (EL) is given. The analysis is limited to phosphors of (activated) ZnS type and to intrinsic EL, i.e., EL excited in condenser type cells, filled with powder phosphors embedded in a good dielectric medium. A new technique, suggested for studying the behaviour of the EL., consists of applying to the cells single transients of voltage (respectively rising or falling) with a constant rate of variation vs time. The circuits used for this technique are described, as well as the preliminary results obtained with commercial EL cells. These results are of a good quantitative character.

33. Bonfiglioli, G.
PROCEEDINGS OF THE INTERNATIONAL CONFERENCE ON COLOR CENTERS AND CRYSTAL LUMINESCENCE, 8–12 SEPTEMBER 1960, SPONSORED BY THE ASSOCIAZIONE NAZIONALE GALILEO FERRARIS AND UNDER THE PATRONAGE OF THE AIR RESEARCH AND DEVELOPMENT COMMAND, U.S.A.F., HELD IN TORINO AT INSTITUTO ELECTROTECNICO NAZIONALE GALILEO FERRARIS. Torino U., Italy.
May 1961. 299p. (AFOSR-982, AFOSR-111, AFOSR TN 59-1255, AFOSR TN 58-917).
ASTIA AD-262 095.

Twenty-five papers were presented at the conference on color centers and crystal luminescence. Eleven countries were represented by the 49 participants. Some of the specific topics were: (1) the Varley mechanism; (2) temperature effects on color centers; (3) defect formation; (4) thermoluminescence; (5) x-ray effects; (6) electroluminescence; and (7) studies on alkali halides.

34. Item deleted.

35. Bukke, E. E.
Measurement of losses in an electro-luminescent capacitor. IZV. AKAD. NAUK SSSR, SER. FIZ. 25(4):529–530, 1961. (In Russian) [English translation in: Bull. Acad. Sci. USSR, phys. Ser. 25(4):526–52 (1961] .

The design of a dynamic wattmeter suitable for measurements luminescent phosphors is described.

35a. Burns, Laurence
Electroluminescent lamp. (Assigned to Syl Electric Products, Inc.) U.S. Patent 3,01 26 Dec 1961. Applied 16 Nov 1956.

The EL lamp is made of two electrodes with an EL substance the following: cadmium oxide, cadmium silicide, copper chlor manganese sulfide, manganese silicide, and zinc selenide. E energy gap of 2-3 electron volts between its valence and condu

36. Cantrell, Gayle Wayne
THE EFFECTS OF VARIOUS DIELECTRIC METHODS OF EXCITATION ON THE LIGH OUTPUT OF ZINC SULFO-SELENIDE ELE LUMINESCENT CELLS. Air Force Inst. o Wright-Patterson Air Force Base, Ohio. Master's thesis. Aug 1960. 74p. (Report GE/EE/60-4).

A standard phosphor was tested in electroluminescent cells wi The brightness of the cells increased as the permitivities of t The exciting voltage and frequency affected the brightness. wave, its peak value, and (when no insulation was provided be its d.c. level affected the light output. The cells had approxi responses, and their light output decreased with age.

36a. Cargill, William W., Jr.
Electroluminescent apparatus. (Assigned to Controls Company of America). U.S. Patent 3,007,070. Applied 1 Feb 1960.

Increased electromagnetic emission is achieved by applying a one-quarter-wavelength thickness of anodized aluminum oxide to electroconductive plates. Further improvement is possible by adding an optional layer of a dielectric such as barium titanate to the anodized aluminum oxide.

37. Caywood, W. P. Jr.
Bistable and low-voltage ferroelectric-control configurations for electroluminescent display devices. In PROC. 1960 NATL. ELECTRONICS CONF. Chicago, Ill., N.E.C., Inc., 1960. p.693-700

Ferroelectric ceramic devices have proven advantageous over competing methods for control of electroluminescent display screens. They have mechanical and electrical properties that are commensurate with electroluminescent cells, and they are economical. The major disadvantage of the present usage of ferroelectric control for electroluminescent display devices lies in the need for large control potentials (100 volts or more) and in the difficulty of obtaining memory of control potential over large periods of time. The technical and economic problems as they exist are discussed in the literature. Recent developments of ferroelectric control configurations allow an extension of the obtainable properties. New regenerative circuits reduce the required control potentials by a factor of ten or more. Bistable circuits allow control signal storage for unlimited periods. Also achievable is an inherent discrimination against control potential changes outside the critical ones, facilitating signal distribution through matrices and facilitating translations such as to alphanumerical digits. In some cases the new circuits reduce considerably the requirements on certain circuit components, compounding their advantages by competition in cost with previous methods.

38. Cerulli, N. F.
ZINC BORATE GLASSES AS DIELECTRICS IN ELECTROLUMINESCENT LAMPS. (Ph.D. thesis) New Brunswick, N.J., Rutgers University, 1958. 106p.

38a. Cerulli, Nicholas F.
ELECTROLUMINESCENT GLASS.
(Assigned to Westinghouse Electric Corp.)
U.S. patents 3,005,721 and 3,005,722.
28 May 1959.

For use in ceramic-type electroluminescent devices, the following composition does not contain components or impurities that would react with or deleteriously alter the electroluminescent phosphor, while it transmits radiations and forms a durable enamel or uniform thickness when fired. Several formulas are given: a typical one contains ZnO 18.1, BaO 37.4, B_2O_3 22.7, K_2O 9.2, Na_2O 4.6, Al_2O_3 3.6, TiO_2 4.1, and Sb_2O_3 0.3%. The glass can be made in accordance with conventional glass-making practice. U.S. 3,005,722. A Zn silicoborate glass suitable for use in ceramic-type electroluminescent devices contains as principal constituents $ZnO \leqq 40$, $SiO_2 \leqq 14$, $Be_2O_3 \leqq 36$, $Li_2O + Na_2O + K_2O \leqq 26$ (in the ratio of approx. 1:4:8, resp.), $BaO + Al_2O_3 + TiO_2 \leqq 22$ with $TiO_2 \leqq 7\%$. This glass has an excellent coefficient of expansion, a low firing temperature, no impurities to deleteriously affect light-generating properties, is non-hygroscopic, has a low power or dissipation factor and high dielectric constant. It is a good insulator and is colorless, transmitting visible and ultraviolet radiations down to 3650A.

39. Coddington, John L. and Robert J. Schipper
Practical solid state three dimensional (3-D)
display. 1962 IRE INTERNATIONAL
CONVENTION RECORD 3:177–184, 1962.

This paper presents a fresh and unique approach for generating a practical three dimensional display. The feasibility of this concept has been substantiated by a demonstrational model which offers a simple approach to dynamically presenting multi-parameters in their true perspective for fast evaluation and decisions concerning complex situations.

An electroluminescent (EL) cross-grid, non-suppressed, matrix panel is the heart of the "3-D" display. When both a vertical and a horizontal line is energized (vertical for range and horizontal for height), their intersection produces a bright spot of light in two dimensions. As the panel is rotated in azimuth about a vertical axis, at a speed of 20 cycles per second above flicker rate, the third dimension is obtained. Electronically pulse gating the EL panel displays floating spots of light representing data or aircraft in three dimensions. These spots appear to be floating within the non-evacuated enclosure.

The paper describes the following: the display design considerations, discussion of the working model, system operation, advantages and limitations, new displays, and concludes with an example of a technique to incorporate this display in the Naval Tactical Defense System (NTDS) or Semi-Automatic Ground Environment (SAGE) System.

40. Corry, T. M.
Designing a low-cost power supply for electroluminescent lamps. ELECT. IND. 21:188-189, Apr 1962.

A low-cost power supply for electroluminescent lamps is described. The design procedure for a simple efficient transistor power oscillator which employs the lamp as a tuned circuit component is also given. Two transistors are connected in push-pull across the primary of a transformer and in series with the dc source voltage. Current feedback is employed and for proper operation the transistors function as switches. However, due to the resonant circuit which includes the secondary winding of the transformer the output current is sinusoidal. The amount of lamp voltage is a function of the dc source voltage, the transformer turns ratio, and the circuit Q.

41. Costin, E.
A new light source; electroluminescence. ENERGETICA (ROUMANIA) 10(2):54-62, Feb 1962. (In Roumaniam)

General description of basic principles, followed by a discussion on applications in the technical and scientific fields.

42. Culp, J. W.
Electroluminescent device for temporary information storage. IRE TRANSACTIONS ON ELECTRON DEVICES ED-9 1:118, Jan 1962.

The feasibility of using electroluminescent elements as memory devices was discussed. This use of electroluminescent elements is based on the fact that such elements have a "memory" of pulse polarity lasting for several seconds. To store a binary 1, the element is supplied with a write pulse of negative polarity. Interrogation is accomplished

with a positive read pulse, and a gated photomultiplier responds to the light output. To store a 0, no negative pulse is supplied. One particular phosphor gave a signal-to-noise ratio of 8 for a storage time of 20 msec and 10 for a storage time of 2 msec. The readout time was 2 μsec. Experiments indicate that high storage density can be obtained in a crossed-grid electroluminescent panel having a nonlinear resistance layer to eliminate cross-talk.

43. Curie, D.
Theories of electroluminescence.
In PROGRESS IN SEMICONDUCTORS
London, Heywood, 2:249–277, 1957.

Theories of three types of electroluminescence of solid crystals are reviewed. These are (a) "pure" or "intrinsic" electroluminescence (Destriau effect), (b) "carrier injection" electroluminescence, and (c) electrophotoluminescence (Gudden-Pohl effect) and other effects. The discussion of (a) includes the mechanism, the excitation process, the kinetics, the supply of electrons to the conduction band, the acceleration process, and conditions for good sensitivity. A brief account is given of electroluminescence of organic substances. The discussion of (b) includes low field phenomena and field emission luminescence phenomena. The discussion of (c) includes the Gudden-Pohl effect and the quenching and enhancing effects of electric fields on photoluminescence.

44. Cusano, D. A.
PHOTOELECTROLUMINESCENCE, ELECTRO-LUMINESCENCE, AND RELATED HIGH FIELD EFFECTS IN ZINC SULFIDE PHOSPHOR LAYERS.
(Ph.D. thesis) Troy, N. Y., Rensselaer Polytechnic Institute, 1959. 172p.

45. Cusano, D. A.
Special phosphor screens for image tubes.
In NASA PROCEEDINGS OF THE (SECOND)
IMAGE INTENSIFIER SYMPOSIUM, FT. BELVOIR,
VA. General Electric Co. Research Lab.,
Schenectady, N. Y., 24 – 26 Oct 1961. p.119–130.
(Contract DA-44-009-ENG-4151) NASA N 62-14890.

Translucent vapor-reacted zinc sulfide layers and cathodelectroluminescence (CEL) intensifying screens are two means of improving the performance of luminescent elements used in image tubes. These layers have been produced with resolutions, measured optically, of up to 115 line-pairs per millimeter. Such layers have exhibited cathodoluminescent efficiencies from 13 to 17 lumens per watt. Although the efficiency resolution product turns out to be the same as for P-20 powder screens, these films should be useful where resolution is more important than efficiency, for example, in multistage image tubes. Vapor-reacted zinc sulfide layers, which exhibit enhancement of luminescence under applied voltage and during electron bombardment, offer up to an order of magnitude of improvement in efficiency resolution. These CEL (cathodo-electroluminescent) screen are brighter than P-20 screens in the range from below 10^{-5} to 10^{-2} microamperes per square centimeter – by more than 10 times at the lower end of this range. A disadvantage of CEL screens for some image tube applications are the long response times when compared to those for P-20 or other simple cathodoluminescent phosphors. The long decay times of CEL screens need not be a similar disadvantage.

46. Damaskova, S.
Course of electroluminescence of Zns: Cu, Mn.
CZECH. J. PHYS. 9(4):529, 1959.

Alternating square-wave pulses were applied to ZnS:Cu, Mn, Al. The brightness waveforms are interpreted as the result of two processes, the direct excitation of Mn centers, and the impact ionization of Cu and Mn centers with transfer of the excitation energy from Cu to Mn.

47. Damasková, S. and K. Pátek
The electroluminescence of ZnS—Cu, Mn.
CZECH. J. PHYS. 11B:336—343, 1961.

An investigation of the brightness waves of ZnS—Cu, Mn phosphor is reported. It has been found that their shape changes from that characteristic for copper-activated phosphors to that characteristic for maganese-activated phosphors as a function of the magnitude of the voltage applied, the length of the pulses and the temperature. In order to explain the results it is assumed that simultaneously with the mechanism of electroluminescence, accepted for ZnS—Cu (ionization of activators; recombination and radiation delayed in phase compared with voltage), there exists an immediate recombination of the Cu activators in the barriers which is accompanied by radiation in phase with the voltage.

48. Diemer, G. and H. A. Klasens
DEVICE COMPRISING A PHOTO-CONDUCTIVE PART AND AN ELECTRO-LUMINESCENT PART.
(Assigned to N. V. Philips) U.S. Patent 2,922,892.
26 Jan 1960.

A technique for improving the contrast in images produced in a light amplifier consisting of an electroluminescent panel in series with a photoconductor is described. The proper contrast is achieved by successively applying to the device two or more alternating voltages, each of which has a different frequency, or by applying an alternating voltage which continuously varies between two frequencies.

49. Diemer, G.
Opto-electronics. PHILIPS TECH. REV.
23(7):189—195, 1961/62.

Opto-electronics is concerned with the interaction of light and electrons in solids, and in particular with "r.e. effects", where optical radiant energy causes a change in electrical properties, and with the alternative "e.r. effects". After discussing photoconductivity, an r.e. effect, the author describes the potential applications and properties — such as power gain and response lag — of (e.r.-r.e.) combinations, and finally deals at greater length with electroluminescence, the most important practical representative of the e.r. effects. The mechanisms of the two known forms, i.e., the Destriau effect and the Lossev effect, are explained with a somewhat parodied version of the band scheme, and it is made clear why high luminous efficiency is possible in principle with the Lossev effect but not with the Destriau effect.

51. Diemer, G. and P. Zalm
The role of exhaustion barriers in electro-luminescent powders. PHYSICA 25(3):232, Mar 1959.

Exhaustion barriers can cause local enhancement of the electric field in insulated electroluminescent crystals, provided that electroluminescent emitting spots are small compared with the local electrode area.

51. Dreeben, A. B., A.G. Fischer, and A. S. Mason
INVESTIGATION OF CARRIER INJECTION ELECTROLUMINESCENCE. David Sarnoff Research Center, Princeton, N. J. Scientific rept. no. 1, 15 Jan–15 Apr 1961. 14 May 1961. 48p. [Contract AF 19(604)-8018] (AFCRL-360). ASTIA AD-259 365.

Injection electroluminescence is the conversion of electrical energy into light energy by way of radiative recombination of electrons and holes which are injected from two separate, ohmic contacts, into the volume of a crystal. Many important applications await the practical availability of injection EL light sources. Since the light source is compact, shock-resistant and cool, it might be suitable for special applications such as laser excitation. The preparation of ZnSe crystals suitable for injection EL is discussed. In order to grow better crystals, several methods were developed for melting selenides and sulfides above atmospheric pressure in selenium or sulfur vapors respectively. A new apparatus for Czochralski pulling of decomposable solids under pressure and experiments with controlled zone-sublimation-recrystallization for vapor-phase growth of ZnTe and ZnSe are described. The design and operation of a new vacuum system for epitaxial growth of multiple layers is outlined.

52. Eriksen, W. T. and H. Ahlburg
An analysis of electroluminescent brightness waves. SOLID STATE ELECTRONICS 3:11–17, Jul 1961.

Using the concept of impact ionization and certain assumptions concerning phase relationships between the applied voltage and exciting electrons an equation giving the time dependence of the instantaneous brightness of electroluminescence is derived. Solutions of this equation are compared to experimental brightness waves and similarities pointed out. The existence of secondary peaks in the brightness wave are predicted without reference to trapping phenomena or delayed recombination.

53. Favorin, V. N. and L. P. Poskacheeva
Dependence of the electroluminescence spectra of certain phosphors on the alternating-field intensity. OPTIKA i SPEKTROSK 7(5):706–709, Nov 1959. (In Russian).

A study of the luminescence spectra of two-color ZnS:Cu:Mn phosphors and of mixtures of green (ZnS:Cu) and yellow (ZnS:Cu:Mn) phosphors in alternating fields. The intensity of the yellow band, due to manganese, rises more rapidly with the applied voltage than that of the green band, due to copper. The lack of interaction between the green and yellow centers is due to the difference of the de-excitation mechanisms of the two types of centers.

54. Favorin, V. N. and G. S. Kozina
Electroluminescence of ZnS:Cu:Mn powders in a constant electric field. OPTICS AND SPECTROSC English Trans: 10(1):43–45, Jan 1961.

Authors give a study of d.c. electroluminescence and electrical conductivity of ZnS:Cu:Mn powders suspended in a mixture of synthetic resins. The electroluminescence brightness was found as a function of an applied voltage and of a conduction current passing through ZnS:Cu:Mn layers. The electroluminescence spectrum was obtained in constant and alternating fields. A mechanism is given which explains the results obtained.

55. Favorin, V.N., G.S. Kozina and I.D. Anisimova
Investigation of the electroluminescence of ZnS:Cu and ZnS:Cu, Mn phosphor layers with excitation by d.c. and pulse voltages. BULL. ACAD. SCI. USSR, PHYS. SER. 25(4):482–486, 1961.(English trans.)

The d.c. electroluminescence of ZnS:Cu and ZnS:Cu, Mn in an organic dielectric is nearly proportional to the current, though varying as about the 10th power of the voltage. The yellow Mn phosphor is much brighter, and was also examined for its response to square wave voltage pulses. Brightness and wave forms were studied under combined d.c. and a.c., when the ZnS:Cu, Mn in particular showed an increase in total luminescence over the sum of separate d.c. and a.c. responses. On the other hand, the brightness of green ZnS:Cu layers under a.c. could be very largely increased by d.c. biasing, whereas ZnS:Cu, Mn was made brighter to a much less extent. ZnS:Cu in enamel coatings showed d.c. electroluminescence when one surface was irradiated by an electron beam and the other (with tin oxide coating) held positive.

56. Favorin, V.N., G.S. Kozina and L.K. Tikhonova
Spectral characteristics of electroluminescence of certain phosphors under the conditions of simultaneous action of direct and alternating fields. OPTIKA i SPEKTROSK 7(5):703–705, Nov 1959. (In Russian)

Two-color phosphors of ZnS:Cu:Mn type, which emit green and yellow bands in alternating fields, as well as mixtures of one-color phosphors, have different electroluminescence spectra in direct and in alternating fields. When the fields are applied together a rise of intensity is observed in the yellow region and the intensity of this yellow luminescence is higher than the sum of intensities due to the action of direct and alternating fields separately; the exact color of electroluminescence depends on the ratio of the d.c. and a.c. fields.

57. Fischer, Albrecht G.
Electroluminescent lines in ZnS powder particles,
1. Embedding media and basic observations.
J. ELECTROCHEM. SOC. 109:1043–1049.
Nov 1962.

Several new embedding media of the same refractive index as ZnS are described which make possible the microscopic examination of the interior of electroluminescent particles taken from efficient industrial lots. Light is emitted in form of lines or striations extending through most of the diameter of the particles. The brightness of single lines has been measured in dependence of applied voltage, frequency, phase, and position along the line. Evidence is presented that the EL lines are associated with invisible copper-sulfide-decorated, conducting imperfection lines of submicroscopic diameter, and that coarse, visible imperfections are not the cause of EL.

58. Fischer, A. G.
Injection electroluminescence. SOLID STATE ELECTRONICS 2:232–246, May 1961.

Previous literature on injection electroluminescence is reviewed briefly. It is shown that the theoretical limit for brightness and efficiency of injection EL can be expected to be higher than that of impact ionization EL. A survey of promising host crystal materials is given, and the unusual difficulties encountered in making junctions in wide-band-gap materials are pointed out. It is concluded that p-i-n junctions offer a more favorable approach to efficient injection EL than p-n junctions. The properties of varied band gaps at the contacts are described and the source of loss is discussed.

59. Fischer, A. G. and A. S. Mason
INVESTIGATION OF CARRIER INJECTION ELECTROLUMINESCENCE. David Sarnoff Research Center, Princeton, N. J. Scientific rept. no. 2, 15 Apr–15 Jul 1961. 15 Aug 1961. 27p. [Contract AF 19(604)-8018] (AFCRL 721) ASTIA AD-264 433.

It was found that vertical crystal pulling of ZnSe and CdS is possible only in pressurized atmospheres of unsaturated vapors, since saturated vapors are too opaque to permit visibility. Several new systems for crystal growth under pressure are described, and a new feedback circuit for control of the RF generator has been invented. The properties of melt-grown ZnSe have been investigated, and an extensive survey of contacts to ZnSe was initiated. ZnSe and CdS form solid solutions, whereas CdS and ZnTe are immiscible. Materials which hold promise for the preparation of alloyed contacts have been found. Several single and multiple films with interesting properties have been obtained by evaporation, and an analysis of SCL hole currents in ZnSe has been carried out. It has been found that a glass consisting of As-S-Br is transparent from .5 to 13 microns GaP crystals have been prepared by vapor phase reaction starting from GaN.

60. Fischer, A. G.
INVESTIGATION OF CARRIER INJECTION ELECTROLUMINESCENCE. David Sarnoff Research Center, Princeton, N. J. Scientific rept. no. 3, 15 Jul–15 Oct 1961. 15 Nov 1961. 34p. [Contract AF 19(604)-8018]. (AFCRL-979). ASTIA AD-270 128.

The use of a new, fast-responding control system in combination with a new setup for the vertical Bridgman method with RF heating under high pressure, effected a marked improvement in the quality of ZnSe crystals. The microscopic observations in single electroluminescent particles were continued. Preparation and properties of the new embedding media with matched indices of refraction are described in detail. Interpretation of the findings permits the elimination of a number of current hypotheses on the mechanism of electroluminescence. The results are in qualitative agreement with a model based on transient alternate space-charge-limited injection of holes and electrons from imperfection lines which are decorated with precipated conducting CuS, into insulating, compensated ZnS. The injected holes are stored in deep activator centers for half a cycle and recombine with electrons in the next half cycle.

61. Fischer, A. G. and A. S. Mason
INVESTIGATION OF CARRIER INJECTION ELECTROLUMINESCENCE. David Sarnoff Research Center, Princeton, N. J. Semi-annual scientific rept. no. 1, 15 Oct 1961 – 15 Jan 1962. [Contract AF 19(604)-8018] (AFCRL 62-142). ASTIA AD-274 948.

A study was made of carrier injection electroluminescence. It was found that electroluminescence in ZnS-type powders occurs in the interior of the particles and is confined to sharp lines of various shape. The brightness of single lines rises exponentially with voltage and becomes linear at highest voltages. Light is emitted at that end of a line which is pointed towards the electrode becoming positive. Existing theories are shown to be insufficient. A new model based on alternating bipolar field-emission from conducting imperfection lines in insulators with traps was developed and compared with experience. Good agreement with most experimental facts is demonstrated. The brightness of single lines (100,000 ft-lamberts) should be obtainable in larger areas with dc injection EL in single crystals since the working mechanism is similar. New insights were gained into the mechanism of depreciation of EL cells. The particle-size-dependence of brightness can be explained. Contact-, dc- and photoelectroluminescence can be interpreted under one common viewpoint.

62. Fischer, F.
Electroluminescence. NATURWISSENSCHAFTEN 49(6):124–126, 1962. (In German).

A brief review of the fundamental processes, observed characteristics and applications in light amplifier and switching devices is given.

63. Fok, M. V.
Electroluminescence. SOVIET PHYSICS-USPEKHI 3(6):832–839, May–Jun 1961. (English trans.)

A review of the electroluminescence of crystalline substances in which the basic distinction between this and other types of luminescence is emphasized. Attention is directed to the origin of the free charges which are responsible for the transfer of energy from the applied electric field to the phosphor and to the methods by which this charge transfer may be achieved. The position of the luminescence centers, the phase of the act of emission relative to that of the applied voltage and the regulation of the

luminescence by the applied voltage are also discussed. The electroluminescence of p–n junctions, or the rectifying junctions between a phosphor and electrodes in contact with it, is described. Recent Russian work on the crystallite electroluminophor ZnS activated with Cu, Nd, Er, Mn or Al and on the microscopic investigation of the glow of single crystals of ZnS is surveyed. Finally some brief mention is made of some practical applications of electroluminescence.

64. Fok, M. V.
The Relation between the blue and green bands in the electroluminescence of ZnS:Cu phosphors.
OPTICS AND SPECTROSC. (English Trans.)
11(1):50–3, Jul 1961.

An approximate calculation is performed for the recombination interaction of the centers of blue and green luminescence of the ZnS: Cu phosphor in the presence of an electric field. It is shown that the action of the field greatly complicates the effect being studied.

65. Fredericks, W. J.
Very low frequency excitation of electroluminescence. BULL. AM. PHYS. SOC., SER. II, 5:187, 21 Mar 1960.

Electroluminescence brightness waves produced by very low frequency excitation were studied. A symmetrical sawtooth voltage was applied to electroluminescence cells of a ZnS , ZnO , Cu , Ag , Cl phosphor. Measurements of the brightness waveforms and phase as a function of excitation frequency in the range from 0. 02 cps to several hundred cps, and in temperature range from 273° to 450°K were made on cells. These cells had the phosphor embedded in a slightly conducting medium so that the average field across the phosphor was approximately equal to and in phase with the average field applied to the cell. At low excitation frequencies the emission of this phosphor was predominantly in a green band at 5200 A. At room temperature with low frequency excitation the maximum in the brightness wave occurred before the voltage maximum. As the excitation frequency was increased the brightness wave maximum occurred later with respect to the excitation voltage, and finally followed the voltage maximum. As the temperature was increased the brightness wave maximum occurred earlier.

66. Frerichs, R. and I. Liberman
Electroluminescence at point contacts in cuprous oxide and the mobility of Cu^+ ions at room temperature. PHYS. REV. LETTERS 3(5):214–15, 1 Sep 1959.

Observations of room-temperature electroluminescence of Cu_2O were used to measure the mobility (5×10^{-10} cm^2/V sec) of Cu^+ ions. Cu^+ vacancies involved in the emission are moved from the Zn cathodes, where the emission occurs, to the Pt anodes by the same field which produces the electroluminescence.

67. Fridkin, V. M., A. N. Bogatyrev and É. V. Brakhman
A parallel study of depolarization and electroluminescence of ZnS photoelectrets. FIZ. TVERDOGO TELA (USSR) (In Russian) 2:2185–90, Sep 1960.

Alternating fields depolarized ZnS:Cu photoelectrets and produced electroluminescence; electroluminescence caused further depolarization. The results are interpreted in terms of two types of local level: shallow and deep ones, responsible for dark and photopolarization, respectively.

68. Fridkin, V. M.
On the luminescence of charged polycrystalline ZnS layers under the action of D. C. electric fields. OPTICS AND SPECTROSC. (USA) 11(1):54–8, Jul 1961.

Luminescence was detected in zinc sulphide electrets under the action of a d. c electric field whose direction was opposite to that of the polarizing field. It was also found that the intensity of this luminescence can be weakened by irradiation of the electret (quenching effect). This effect was used as the basis of a new photographic process.

69. Fritzsche, C.
Investigations on the steepness of luminance – voltage curves of electroluminescent ZnS phosphors. JENAER JAHRBUCH (In German) I:309–19, 1960.

Phosphors were tested in a castor oil cell at 800 c/s. The slope of the luminance–voltage curve $B = a_1 \exp(-b_1/V^{1/2})$ changes with the concentration of phosphor in the layer, while with increase of Cu in the material the B-V relation changes towards $B = a_2 V \exp(-b_2/V^{1/2})$. Increase of Cl in the phosphor increases the value of b_1. When separate emission bands are measured, the values of b may increase or decrease with wavelength of the band. Reasons for this are discussed.

70. Gee, A.
Electrochemiluminescence at a silicon anode in contact with an electrolyte. J. ELECTROCHEM. SOC. 107:787–8, Sep 1960.

Luminescence was observed during anodic oxidation of stain films on p-type silicon. This luminescence occurs in the part of the plateau in the voltage/time curve representing a time when a sharp voltage increase is observed with a constant current source. No successful correlation of quantitative data with such parameters as film thickness was established. This luminescence was not observed with n-type silicon.

71. Gelling, W. G. and J. H. Haanstra
A red electroluminescent ZnSe phosphor. PHILIPS RES. REP. 16:371–5, Aug 1961.

The preparation of electroluminescent phosphor, consisting of zinc selenide activated with copper and aluminium, is described. At higher frequencies (1500 c/s) the quantum output proves to be equal to the quantum output of a standard green ZnS(Cu, Al) electroluminescent phosphor under the same operation conditions.

72. Georgobiani, A. N. et al.
Absorption of energy in electroluminescence. OPTIKA i SPEKTROSKOPIYA (In Russian) 12:564–68, 1962.

73. Georgobiani, A. N.
Electroluminescence excitation process in ZnS.
OPTICS AND SPECTROSC. (USA) Vol. 11,
No. 3, 231–2, Sep 1961.

Experiments carried out with 500 c/s pulsed voltages on electroluminescent ZnS condensers indicated excitation can take place either by electron impact (a process lending to avalaunch breakdown) or by direct field excitation (the tunnelling of valence electrons into the conduction band: Zener effect).

74. Georgobiani, A. N. and M. N. Fok
Main peaks in the light pulses of electroluminescence. OPTICS AND SPECTROSC. 9:407–411, Dec 1960.

By investigating the shape of the light pulse, it is shown that at high voltages the process of electron release is regulated basically by the field. Electron liberation takes place at low temperatures by collision ionization and at high temperatures by tunneling through a potential barrier (Zener effect). A comparison of experimental and theoretical temperature dependence curves of the fields at which a total release of electrons is obtained has made it possible to calculate the value of optical phonon obtained from the vibrational structure of the edge emission spectrum, and with the energy depth of levels calculated from the equilibrium concentration of donor free electrons in an electroluminescent ZnS-Cu crystal.

75. Georgobiani, A. N. and M. V. Fok
The phase of electroluminescence light pulses as a function of excitation voltage parameters.
OPTICS AND SPECTROSC. 11:48–50, Jul 1961.

This was investigated as a function of the amplitude and frequency of the exciting sinusoidal voltage. Experimental results are compared with theoretical data calculated on the assumption that the light pulse is formed as a result of the liberation of trapped electrons by an electric field. From a comparison of theoretical and experimental data, the depth of the trapping levels was estimated to be $\Delta = 0.64 \pm 0.07$ eV.

76. Georgobiani, A. N. and M. V. Fok
The process responsible for the voltage dependence of the mean luminescence brightness. OPTICS AND SPECTROSC (USA) 10:95-97, Feb 1961.

Though the main peak of electroluminescent emission probably depends on release of trapped electrons, the voltage dependence of the mean value of the emission was explained as a result of impact ionization. An examination of the probability of this process shows that the observed voltage dependence should occur only in a voltage range below that used. Temperature effects also are not in agreement with the former hypothesis. The experimental data can be explained by the tunneling of electrons through a barrier, possibly from the valency band of a surface phase of Cu_2S to the conduction band of ZnS. A zone scheme is devised for Cu_2S and ZnS in contact.

77. Gershenzon, M. and R. M. Mikulyak
Electroluminescence at p-n junctions in gallium phosphide. J. APPL. PHYS. 32:1338-1348, Jul 1961.

The preparation of both diffused and alloyed junctions from single crystals of GaP is described. The diodes are characterized by their current-voltage relationships and their capacity at reverse bias. Anomalies in both the forward and the reverse currents, an excess capacity, and a hysteresis effect are attributed to the presence of deep centers in the depletion layer, particularly in the alloyed structures. A nearly compensated layer was found at the junction of the diffused diodes. The spectra, bias dependences, decay times, and efficiencies of the electroluminescence emitted at these junctions at both forward and reverse bias were studied and correlated with the diode models. At reverse bias, radiative intraband relaxation was due to carriers excited during avalanche breakdown (diffused diodes), by internal field emission (alloyed diodes), and from carriers thermally generated within the depletion layer (all diodes). At forward bias, only the diffused junctions exhibited light emission and this was of two types: (1) a band-to-band recombination with phonon cooperation, whose recombination kinetics depended on whether or not the process occurred within the depletion layer, and (2) recombination through a deep level which may be associated with a vacancy.

78. Gillson, J. L., Jr. and F. J. Darnell
Electroluminescence in zinc sulfide.
PHYS. REV. 125:149-158, 1 Jan 1962.

Microscopic observations of electroluminescent emission from ZnS crystals activated with Cu, Cu:Pb, or Ag showed that the typical emitting entity is a narrow line. These lines lie in [11·0] directions of the wurtzite structure in planar regions associated with stacking faults or closely spaced alternations in crystal structure. A model of electroluminescence involving linear physical defects is proposed for the origin of the lines and their observed dependence on voltage, frequency, and phase of the applied field.

79. Gobrecht, H. and H. E. Gumlich
On the enhancement and quenching of the luminescence of manganese-activated zinc sulphides by electric fields. Z. PHYS. 156:436-455, 1959. (In German)

Results are reported for ZnS with a range of Mn activator concentrations, tested in the usual electroluminescent cell. In general, the short wavelength end of the emission to X-rays or ultraviolet is diminished by an applied a.c. field, whereas the yellow emission is increased for preparations with certain Mn concentrations. Details are given of the effects of different field frequencies and different excitation intensities. The enhancement or quenching increase with field increase, but at less than a linear rate; presumably part of the energy lost from the "blue" centers is transferred to the "yellow" ones.

80. Gobrecht, H. and H. E. Gumlich
The influence of the excitation wavelength on electrophotoluminescence. Z. PHYS. 158:226-241, 1960. (In German)

The energy level structure of ZnS:Mn and its luminescent and non-radiative transitions are discussed. Excitation spectra are given for the Mn band and the lattice band at Mn concentration between 10^{-2} and 10^{-5} by weight. The yellow emission is enhanced by an electric field if the ultraviolet excitation is absorbed in the lattice band, while quenching is caused if excitation occurs in the long wavelength tail of the lattice absorption; the field has no effect if the ultraviolet is absorbed directly by the Mn ions. The blue emission is decreased by the field whether excitation is above or below the absorption edge. The mechanism is discussed in terms of energy transport.

81. Goffaux, R.
Electrical properties of powders of electroluminescent ZnS. J. PHYS. RADIUM.
20(Suppl. No. 4):18A–22A, Apr 1959.
(In French)

The current-voltage characteristic of electroluminescent powders of zinc sulphide excited at 50 c/s is similar to that of a varistor. The effective impedance of the electroluminescent layer can be represented by a variable resistance R_p connected in parallel with a variable capacity C_p. An interpretation of the variation of R_p and C_p with applied voltage has been developed on the basis of previous work on the behavior of varistors subjected to an alternating potential. It appears to be in good agreement with the experimental results. The distinction between electroluminescent and non-electroluminescent phosphors is suggested to be due essentially to differences in free electron density and the associated possibility of an electron temperature appreciably higher than the lattice temperature.

82. Goffaux, R.
Luminance waves in electroluminescent cells.
J. PHYS. RADIUM 23(Suppl. No. 3):1A–6A,
Mar 1962. (In French)

An electroluminescence process is suggested, based on a collective model, and using the comparison between the shape of the current waves through the varistances and the shape of the luminance waves of the electroluminescent cells, supplied by alternating voltage. This process takes account of the variation law of the luminance as a function of the excitation frequency. It is suggested that the luminescence could be produced by a recombination through two stages: the almost instantaneous recombination between liberated electrons and excited or ionized luminous centres and the delayed recombination between luminous centres with electrons coming back by diffusion from places where they were gathered by the electrical field. The discussion of the variations of the luminescence L as a function of the excitation frequency ν, in the low frequencies range, showed that $L \sim \nu^n$, where $1/2 < n < 1$, but that the more rational law would take an exponent approximately 1.

83. Goldberg, P. and S. Faria
On the physical characteristics and chemical composition of electroluminescent phosphors.
J. ELECTROCHEM. SOC. 107:521–526, Jun 1960.

Through controlled removal of surface layers, it was found that surface chemical barriers are not responsible for electroluminescence in zinc sulphide phosphors. Polycrystalline phosphors are shown to be almost uniform with respect to chemical, physical, and electroluminescent properties as one passes from the surface into the crystallite bulk. Electron micrographs show the character of the particles as successive layers of phosphor surfaces are removed by acid etching. The experimental results at progressive stages of eteching are interpreted in terms of an inefficient surface layer and of decreased particle after eteching. Regions capable of serving as the site of field intensification are held to exist throughout the volume of the particles.

84. Goldberg, P.
The action of nickel and cobalt in electroluminescent zinc sulfide phosphors. J. ELECTROCHEM. SOC. 106:948–954, Nov 1959.

Nickel and cobalt produce many of the effects in electroluminescent phosphors that are known for photo- and cathodoluminescent ZnS. In addition, these elements bring to electroluminescent phosphors other changes in properties which are of practical and theoretical interest. Among these are (a) enhancement of emittance in blue-emitting phosphors, (b) marked changes in emittance-voltage and emittance-frequency characteristics, and (c) simplification of the brightness waveforms. The frequency and brightness wave effects can be understood in terms of "fast" and "slow" recombination processes which are influenced differently by the iron-group elements. The enhancement of electroluminescence is of uncertain origin but may arise from changes in the photocapacitive properties of the powder crystals due to the iron-group elements. The similarities and differences of nickel and cobalt in both blue and green-emitting phosphors are discussed.

85. Gol'dman, A. G.
A new electroluminescence effect in black carborundum. DOKL. AKAD. NAUK SSR 135:1108-1110, 11 Dec 1960. (In Russian)

The voltage dependence of light intensity for electroluminescence emission from black SiC was studied. The measurements include observation of intensity as a function of frequency for pulsed excitation with various pulse magnitudes. In addition, a third type of emission is reported whose intensity is independent of pulse frequency and arises in the region of electron injection. It differs from the other emission associated with injection, which occurs while the voltage is applied, in that it becomes visible after the voltage is reduced to zero. The color of this emission is different from that of the other two kinds of electroluminescence in carborundum.

86. Gol'dman, O.G., V.P. Dudnyk and O.I. Proskura
The frequency characteristics of the brightness of electroluminescent cells with zinc-sulphide powder electroluminophors. UKRAYIN. FIZ. ZH. USSR 6:761-764, 1961. (In Ukrainian)

The authors studied cells with an electroluminophor layer in air (the electroluminophor was sifted on a metal electrode, a transparent electrode was clamped to it, and insulation was secured by means of mica packing). The current through the cells was proportional to the frequency, so that the equivalent electric circuit for the cell was represented with sufficient accuracy by a capacitor circuit. The frequency characteristic of the brightness B of the cell with a constant value of the voltage was defined approximately by the relationship $B = af^k$, where k ranges in value between 0 and 1. On switching into the generator circuit, an electroluminescent cell with resistance, capacitance, inductance or their combinations, the frequency dependence of the brightness of the cell with a constant generator voltage is defined chiefly by a dependence on the frequency of the voltage exciting the cell. Therefore, the frequency dependence of the cell brightness may be given the desired form, extreme examples of which are, on the one hand, an almost constant value of the brightness over some frequency interval, and, on the other hand, an acute, resonance-type, selective dependence on frequency. The efficacy of using electroluminescent cells in resonance operating conditions is pointed out.

87. Gomez, A. D.
DESIGN, DEVELOPMENT AND CONSTRUCTION OF ONE ELECTROLUMINESCENT SONAR DISPLAY. Straza Industries, El Cajon, Calif. Quarterly interim development rept. no. 1, 1 Jun–1 Sep 1961. 1 Sep 1961. 33p. (Contract NObsr-85430). ASTIA AD-263 622.

The purpose of this program is to design, develop and construct one (1) prototype solid state sonar display device. The display device will employ the phenomenon of electroluminescence and photoconductivity in a layerized method of construction. Progress during this period is related to improvement of the stability and reliability of the constituent layers in the display device. Due to the fact that this display was conceived and constructed during a company sponsored program, a great deal of the technology necessary for fabrication has been created and tested, but each of the layers of the display interacts with adjacent layers hence better and more detailed testing is being done. During this period, properties of the glass substrate, NESA coating (stannic oxide) and preliminary design of both the display and the supplementary electronic equipment was begun. Results of some of the tests are incomplete at this time and will be included in later reports.

88. Gomez, A. D.
DESIGN, DEVELOPMENT AND CONSTRUCTION OF ONE ELECTROLUMINESCENT SONAR DISPLAY. Straza Industries, El Cajon, Calif. Quarterly interim development rept., 1 Sep–31 Dec 1961. 31 Dec 1961. 39p. (Contract NObsr-85430). ASTIA AD-271 626.

Display processing studies were conducted to gain a better understanding of the physical and electrical properties of the various layers to be incorporated in the display device. Work was performed on the NESA layers and their processing, on the photoconductive layer, and on the measurement of the EL brightness vs. voltage for the determination of the electrical properties of the support electronics. Display technology efforts included finalizing the fabrication techniques and chemical etching of the NESA films to the required geometry. The proposed technique for connection to the display and the current technology in the preparation of the optical cross-talk layer were studied. The philosophy and the initial design phases for the sustained supply and the analyzer amplifiers are presented. The optical programmer for the azimuth information to the display is also discussed.

89. Greguss, P. and J. Weissburg
The electroluminescent panel in an ultrasonic field. ACUSTICA 9:183–184, 1959.

When a panel normally of blue-green electroluminescence is exposed to ultrasound, the affected parts show a persistent yellow electroluminescence. This is probably due, not to the ZnS phosphor, but to $BaTiO_3$ or other material of high dielectric constant which is mixed with the phosphor.

90. Grigor'ev, N. N. and Yu. A. Kulyupin
Deterioration of a phosphor during electroluminescence. OPTICS AND SPECTROSC (USA) 10:412–415, Jun 1961.

The process of deterioration of a ZnS – ZnO:Cu, Al, Cl electroluminor was studied in a cell whose construction made it possible to change the disposition of the active particles without changing the effective volume or the conditions of excitation. The brightness of photoluminescence and electroluminescence, the intensity ratio of the "blue" and "green" bands, and the components of the light pulse were measured simultaneously at different stages of the deterioration process. According to these measurements, the phosphor damage may be considered local. It manifests itself to a greater extent at the surface and is not connected with any decrease in the number of luminescence centers. There are changes in the frequency characteristic and in the dependence of brightness on voltage. The results obtained are explained satisfactorily by a decrease in the efficiency of the process of electroluminescence caused by growth of the space charge region.

91. Grigor'ev, N. N. and Yu. A. Kulyupin
Some results of an investigation of the deterioration of phosphors during electroluminescence. BULL. ACAD. SCI. USSR PHYS. SER (USA) 25:522–523, 1961.

The deterioration is attributed to the buildup of space charge regions in the phosphor crystals and consequent reduction of internal field.

92. Gutjahr, H. and F. Matossi
Dependence of the electrophotluminescence of a ZnCdS phosphor on exciting wavelength and field pulse width. Z. PHYS. 162:105-113, 1961. (In German)

Luminescence flashes in an excited ZnCdS : Ag phosphor occur when electric fields are switched on or off. Whether these flashes are positive or negative depends on the length of the field pulse, on the exciting wavelength, and on the polarity of the irradiated electrode. There is a critical duration of the field pulses for which no field-off flash appears. At another, but related, critical time, the flashes change sign under the application of a periodic field. These times change with the exciting wavelengths. The observations are interpreted as being controlled by the gradual filling of surface traps, which in its turn is influenced by the distribution of electron and hole concentrations produced by the incident radiation and the electric field. The critical time is approximately equal to the time needed for completely filling the surface traps.

93. Gutjahr, H.
Gudden-pohl effect in a zinc cadmium sulphide.
Z. PHYS. 168:199-205, 1962. (In German)

Luminescence flashes in an excited ZnCdS:Ag phosphor occur when electric fields are put on. At -120°C such flashes also occur if the electric field is applied some time after excitation is removed. The intensity depends on additional fields acting while the phosphor is excited by the light. The observations can be interpreted if the flashes are assumed to arise near the surface instead of the interior of the phosphor.

94. Hadley, C. P. and R. W. Christensen
Solid-state image intensifier under dynamic operation. R.C.A. REV. 20:670-681, Dec 1959.

Describes the performance of photoconductor/electroluminescent-phosphor image intensifiers under dynamic conditions of operation. Both experimental data and theory are presented. The theory is based on some simplifying assumptions which allow easy analysis and permit an insight into the importance of the various parameters. The experimental data, however, confirm the applicability of the analysis. Some suggestions concerning the possible improvement of intensifier performance are made.

95. Halpin, A. T. and P. Goldberg
Effects of interaction among particles in electroluminescent layers. J. ELECTROCHEM. SOC. 108:1028-1034, Nov 1961.

The optical and electrical behaviour of electroluminescent layers are discussed in terms of experimentally determined properties of individual phosphor grains modified by interactions with neighbouring particles. Pronounced interaction effects were found and were studied by determining the dependence of cell brightness and electrical dissipation on variables that alter the degree of particle-particle interaction, i.e. phosphor volume fraction and fluidity of embedment medium. One result of interaction between particles is to increase the average luminous flux per unit volume of phosphor as volume fraction increases. A statistical analysis is given which correctly describes this effect in terms of the number of particles in contact in the layer. The role of particle interaction in determining the dielectric properties of the phosphor is evaluated for two purposes: (a) To test the validity for electroluminescent layers of theoretical formulae that give the dielectric constant of mixtures in terms of component properties and volume fractions, and (b) to evaluate intrinsic phosphor efficiency at infinite dilution (zero interaction). It was found that the dielectric mixture formulae apply only at very low volume fractions and that phosphor efficiency falls with decreasing volume fraction.

96. Hamburger, T.
Electroluminescent alphanumeric display.
ELECTRONICS 33:49-51, 22 Jan 1960.

A displaying typewriter is described. Electroluminescent materials are used to form alphanumeric indicators, which are excited by ferroresonant switching circuits. A nonlinear iron-core inductor in series with an ordinary capacitor presents a bistable a-c v-i curve, and can be used for information switching and storage. The alphanumeric indicators consist of segments of dielectric-imbedded phosphors sandwiched in transparent conducting material. Each segment appears as a lossy capacitor, facilitating the use of the display as a portion of the information storage circuit. A typewriter may be connected to supply trigger signals to the proper segments, so that an electroluminescent display of the typed information may be achieved. Erasure may be selective or display-wide.

97. Hamburger, T.
Electroluminescent typewriter. PROC. NEC
15:575–584, 12–14 Oct 1959.

A new display system utilizing electroluminescent alphanumeric indicators and ferroresonant storage and switching is discussed. A present embodiment of the system consists of a standard typewriter keyboard upon which information is entered and a sequential display panel, with a capability of five characters, where the information appears. Possible uses are: (1) to read-in or read-out computer information, (2) as a display board, or (3) for communication between two or more remote locations.

98. Harman, G. G. and R. R. Raybold
Measurement of minority carrier lifetimes in
SiC by a novel electroluminescent method.
J. APPL. PHYS. 32:1168, Jun 1961.

A method of measurement of the minority carrier lifetime of semiconductors with large energy gaps in which carriers are injected via a poor contact or rectifying junction until recombination produces a constant electroluminescent output is described. When the frequency approaches the carrier lifetime, the intensity decreases sharply. The method requires only simple equipment such as a variable frequency generator, an RF voltmeter, a photomultiplier, and a dc microammeter. No special size or crystal shape is required, subject to the limitation that the crystal should be longer than the minority carrier.

99. Harper, W. J.
Some effects of the electric contact in films of
electroluminescent ZnS:Cu:Cl. J. ELECTRO-
CHEM. SOC. 109:103–109, Feb 1962.

A low-conductivity layer placed between a conducting electrode and a film of evaporated electroluminescent ZnS:Cu:Cl phosphor has a pronounced effect on the properties of the cell. The logarithm of the integrated brightness varies inversely as the voltage or as the square root of the voltage, or their combination depending on the electric contact and on the conditions of excitation. Three brightness peaks may be obtained in each half-cycle of alternating voltage, one substantially in phase, the other two delayed. The in-phase brightness peak is accompanied by some rectification of current. The direction of greater current is determined by the nature of the contact and the conditions of excitation.

100. Henck, R. and A. Coche
Modulation of the luminescence excited by α-rays in certain zinc sulphides under the action of alternating fields. J. PHYS. RADIUM 22:59-60, Jan 1961. (In French)

Blue and orange emission bands from 88ZnS:12CdS:Mn under α-rays behave differently when an a.c. field is applied. Somewhat unsymmetrical light waves with two maxima per cycle of the field are superimposed on the steady α-ray luminescence. For the orange band the whole wave is above the former level, its minima occurring when the applied field is near zero. For the blue band the average luminescence is reduced by the field, though the maxima of the light waves are above the level for α-ray excitation alone, and these maxima occur near the times of zero field.

101. Henck, R. and A. Coche
The intensifying effect of electric fields on α-ray luminescence as a function of the emission wavelength and the frequency of the electric field. J. PHYS. RADIUM 22:98-100, Feb 1961. (In French)

The intensifying effect of electric fields on α-ray excited phosphors of the type ZnS:CdS activated with Mn, was studied as a function of the emission wavelength of the phosphor and of the frequency (0.005 c/s to 50 kc/s) of the applied electric fields, for several concentrations of manganese.

102. Henisch, H. K.
ELECTROLUMINESCENCE. N.Y., Pergamon, 1962. 368p.

103. Henisch, H. K. and B. R. Marathe
A note on electroluminescence due to carrier accumulation. PROC. PHYS. SOC. 76(Pt 5):782–783, Nov 1960.

Low's suggested mechanism of minority carrier accumulation under a field may be involved in electroluminescence. This could occur in an n-type region adjacent to an n^+ region to which current is flowing. In contrast to the carrier injection case, recombination luminescence would occur near the cathode and to a depth decreasing with increase of the field.

104. Henisch, H. K.
Electroluminescent devices. BRIT. J. APPL. PHYS. 12:660–667, Dec 1961.

A survey of recent progress in the applications of electroluminescence, dealing with panels for illumination purposes, with alpha-numerical indicators, with light and picture amplifiers of various kinds and scanned picture displays.

105. Hoffman, G. R. and P. L. Jones
Electroluminescent fixed store for digital computer. INSTN. ELEC. ENGRS-PROC. (Electronic & Communication Eng) 109B(44):177–183, Mar 1962.

Method of reading information from electroluminescent digital store makes use of nonlinear electro-optical property of electroluminescent cells to provide modulation; operation of matrix containing 128 × 128 digit positions.

106. Hoffman, G. R. and D. H. Smith
The light waveforms emitted from electroluminescent cells energized by square waves and pulses of voltage. J. ELECTRONICS AND CONTROL 9:161–216, Sept 1960

Light pulses which rise to a maximum in less than 0.2 μs can be obtained from electroluminescent cells excited by voltage waveforms with fast edges. The pulses decay more slowly, taking from 2 to 3 μs at a p.r.f. of 50 kc/s and about 100 μs at 200 c/s, to decay to one-third of the maximum amplitude. The dependence of this maximum amplitude on the peak value of the voltage obeys a similar law to that already found for the average brightness of a cell. These and other features of the light pulses depend on the time-variation of the electric field strength within the phosphor crystal. The waveform of the electric field is quite different from the applied voltage and can be regarded as having two components due respectively to the applied voltage and the internal space charge which is built up during the first few cycles of excitation. The former can be found approximately from a simplified equivalent circuit, and information about the latter can be obtained form a consideration of the part played by electron traps in the mechanism of electroluminescence.

107. Hook, H. O.
Optical feedback type storage light intensifiers.
R. C. A. REV. 20:744–52, Dec 1959.

Three designs of storage light intensifiers were evaluated by building samples. One design uses a Fotoform glass structure to support the photoconductor and electroluminor and to provide optical isolation of cells. Another uses a transparent (glass or plastic) multiple pedestal structure to provide light paths through the photoconductor and support the active materials. The photoconductor itself provides the optical isolation. The third design uses a flat glass plate as a support, the active materials and optical isolation being built up in layer fashion. Devices of the last type worked best. Typical operation provided optical trigger of 0.1 lm/ft^2 sec, half-hour storage and 0.1 sec erasure in a 12 in.^{2} panel with 250 000 storage cells. With suitable operating conditions, half-tone pictures could be displayed for 1 min. or longer.

108. Hook, H. O. and E. C. Giaimo
RESEARCH ON OPTO-ELECTRONIC COMPUTER COMPONENTS. David Sarnoff Research Center, Princeton, N. J. Final rept. 1 Jan 59 – 31 Oct 60. 30 Nov 60. 61 p. (Contract AF 19(604)4959)

Opto-electronic digital circuits using electroluminor and photoconductor components have, with present materials, minimum switching times of approximately 50 millisec. Although per-element powers are about 10 to -5 watt the low speed prohibits the practical use of opto-electronic circuits in arithmetic circuits. In input, output and image processing, however, the advantages of parallel processing using neighborhood interaction, threshold logic and negation seem to more than overcome the relative slowness of each cell. Line thinning and thickening, hole fill-in. outlining or fimbriation, motion detection intersection detection, and negation were demonstrated, and de-noising, speck removal, and character simplification seem feasible. Special photoconductor cells may provide an input to a high speed non-scanning character reader. (Author)

109. Iizima, S. and M. Kikuchi
Electroluminescence in gallium phosphide single crystals. J. PHYS. SOC. JAPAN, 16:1784–1785, Sept 1961.

Current-voltage characteristics and electroluminescence observed in point contact GaP diodes fabricated from GaP crystals prepared in argon at elevated temperatures are discussed. Good rectification characteristics were obtained. An orange-yellow emission was observed at breakdown, i. e. , about 5 to 10 volts. The emission appeared over the whole crystal but is probably due to the internal reflection of the light emitted at the point contact. No electroluminescence was observed with forward bias, probably due to the presence of "deathnium" levels produced by the large amount of impurities unintentionally introduced into the crystals. The current versus light intensity data suggest that bimolecular radiactive recombination is the principal cause of the emission.

International Business Machines Corp.,
Kingston, N. Y.
DISPLAY IMPROVEMENT PROGRAM.
VOLUME II. Final rept. vol. 2 on ECPX
0027. 1 Nov 1960. 396p. incl. illus. tables,
55 refs. (Contract AF 30(635)1404).
ASTIA AD-253 401.

Several approaches to the development of luminescent materials to be utilized in the fabrication of a display panel were investigated: (1) the Kerr effect, (2) optical pumping, (3) the Faraday effect, (4) ionized gas effect, (5) electrolytic effect, and (6) electroluminescence. The combined phenomena of electroluminescence and photoconductivity indicated the greatest potential, and therefore was investigated in greater potential, and therefore was investigated in greater detail. The final result of this task was the design of an improved Display System and the fabrication of a Display Feasibility Model. This Display System incorporates a newly designed, brighter CRT, while control of the repetition cycle permits a stable display in high ambient light conditions. Solid state components are employed to increase reliability and life of electronic components, while reducing power and space requirements. The transformer logic circuitry developed for the Display System is capable of 5.5-mc operation, permits a substantial reduction in the number of transistors required (thus lowering cost and improving reliability), and is extremely flexible. (Author)

111. Ivey, H. F.
IMPROVED RED ELECTROLUMINESCENT
PHOSPHORS. Westinghouse Electric Corp.,
Bloomfield, N. J. Rept. for June 1960–
May 1961 on the Chemistry and Physics of
Materials. Dec 1961. 128p. (Contract AF
33(616)7350, Proj. 7360). (ASD TR 61-167).
ASTIA AD-272 786.

A large number of elements were tried for their possible effect as activators of red emission in ZnS. Considerable effort was given to the ZnS:Cu, Tl, ZnS:Cu, Li, Ti, and ZnS:Cu, Fe, I systems, all of which showed some potential as red emitters. A development possibly leading to an improved red electroluminescent phosphor was that of treatment of hexagonal (Zn, Cd)S:Cu, I phosphors in I vapor. The best phosphors of the desired color made in this way had a quantum efficiency about 25% of that of convential green-emitting cubic ZnS:Cu, Cl phosphors and a brightness about one-third that of a cubic (Zn, Cd, Hg)S:Cu. In phosphor. The best red-emitting electroluminescent phosphor known therefore was still (Zn, Cd, Hg)S:Cu. As a result of improvements in plastic dielectrics for embedding the

phosphor and in voltage breakdown protection by use of layers containing $BaTiO_3$, considerably higher brightness was obtained. (Author)

111A. Ivey, H. F. and W. A. Thornton
Preparation and properties of electroluminescent phosphors for display devices. IRE TRANSACTIONS ON ELECTRON DEVICES ED-8:265–279, 1961.

Electroluminescent phosphors for use in some electronic display devices should have brightness-voltage characteristics differing from those used in light sources, for example. The various factors of phosphor preparation and of cell construction which affect these characteristics have been studied. Special phosphor powders with unusually high or unusually low values of "discrimination ratio" (a quantity related to the change in output as the applied voltage is varied) have been developed and their performance described. It has also been shown that thin phosphor films afford extremely high values of discrimination ratio, particularly if operated on dc. The use of nonlinear materials (especially zinc oxide) as auxiliary layers to increase the discrimination ratio obtained with a given phosphor has been studied.

112. Iwersen, J. E., L. A. D'Asaro, E. E. LaBate and P. P. Perron
SOLID-STATE DEVICE RESEARCH CONFERENCE, Durham, New Hampshire. 9–11 July 1962. (Proceedings to be published)

An optoelectronic relay has been constructed. It consists of a forward-biased electroluminescent (EL) GaP diode optically coupled to a reverse-biased photoelectric (PE) Si diode which drives a common-collector Darlington transistor pair. A feedback resistor is connected across the Darlington amplifier to reduce turn-off time (turn-on time is thereby increased). With the feedback adjusted to give approximately equal rise and fall times, the average on-and-off operate time for unity current gain (the time-gain ratio) is less than 50 μsec.

The over-all relay time constant is relatively long because the EL diode is inefficient. This inefficiency must be made up in the succeeding amplifier and rise (or fall) time is the product of amplifier time constant and gain. The current gain of the ELPE diode combination alone is 1.8×10^{-4}. The amplifier time constant in this case is the load resistance (100 ohms times the PE diode capacitance ($\sim$ 20 pf). This leads to a rise time-gain ratio of about ten μsec. The feedback resistor increases this somewhat.

113. Jaffe, P. M.
On the theory of electroluminescence deterioration. J. ELECTROCHEM. SOC. 108:711–12, Jul 1961.

Glow-curve examinations were made of electroluminescent phosphors at various stages in their deterioration. Progressive changes are exhibited in the levels associated with the activator and co-activator. Since these changes cannot be explained by existing theories of the electroluminescence deterioration, the author proposes a new mechanism. This involves field induced diffusion of the halogen donor away from its equilibrium position near the copper acceptor.

114. Johnson, J. E.
Microsecond response of electroluminescent cells. J. ELECTROCHEM. SOC. 108:852–5, Sep 1961.

Microsecond rise of electroluminescent (EL) output to greater than the steady-state value for a. c. sine-wave excitation was achieved in plastic-embedded powder phosphor cells by application of an a. c. burst having a d. c. component. The decay time for the EL flash, 7 μsec, is considerably longer than the rise time. The EL resulting from a. c. bursts of several voltage waveforms was observed. It was noted that: (a) The EL brightness wave rises in one-half cycle of an a. c. voltage burst when a. d. c. component equal to one-half the a. c. peak-to-peak voltage is applied and can exceed the steady-state value, depending on the magnitude of the d. c. pulse. (b) When there is no d. c. component, the EL rises to its equilibrium value in several cycles of the a. c. voltage. (c) The rate of rise of the EL brightness in (b) and the extent of the initial rise in (a) were found to vary with the repetition rate of the a. c. burst. (d) The application of a square wave having the same peak voltage excursions, rather than a sine wave excitation, increases the integrated light-output of the cell. The above were measured, along with the steady-state brightness, at frequencies from 60 c/s to 500 kc/s. From these measurements it is concluded that device applications of EL cells are feasible where fast rise bursts of light are required.

115. Johnson, J. E.
Photoconductive material design for high-speed EL-PC computer elements. Paper presented at SOLID-STATE DEVICE RESEARCH CONFERENCE, DURHAM, NEW HAMPSHIRE, 9-11 JULY 1962. (Proceedings to be published) Abstract appears in IRE TRANSACTIONS ON ELECTRON DEVICES. Nov. 1962. p.504.

Expressions are derived which relate the required operating specifications of an electroluminescent-photoconductive (el-pc) device to the physical parameters of the materials.

115A. Joormann, Hendrik Jacobus Maria, Gesinus Diemer, and Hendrik Klasens
Electroluminescent lamp. (Assigned to N. V. Philips' Gloeilampenfabrieken) Ger. 1,123,399 (Cl. 21f), 8 Feb 1962. Netherlands. Appl. 4 Feb 1960.

A luminescent plate is described consisting of a metal carrier of 50-80% Ni and 50-20% Fe, covered with glass enamel which has imbedded in it ZnS, a transparent layer of SnO, and then protected with a layer of glass. The metal carrier and the conducting SnO phase serve as the poles.

Kaiser Industries Corp., Palo Alto Calif.
INVESTIGATION OF SOLID-STATE DELAY LINES. Final rept. 30 Apr 1962. 107p.
ASTIA AD-275 764

Research was conducted on solid-state display circuitry. Of the two basic items needed for a display panel, a control apparatus and a light controlling medium, efforts were directed only toward the control apparatus. The work has progressed to a point where it stands as a major breakthrough in electronic switching (commutating) or crossed-field (crossed-grid) panels, using electroluminescent phosphor or other light controlling media. The switching system is described, including the digital arrangement which removes the normal limitations on resolution. An automatic phasing scheme is also explained. The 40 × 40 and the 100 × 100 line breadboard displays and the 100

element bar graph are described. Also, covered are the various types of delay lines studied, as well as nanosecond pulse techniques and pulsers, and assembly methods of EL panels. (Author)

117. Josephs, Jess J.
A review of panel-type display devices. Lincoln Lab., Mass. Inst. of Tech., Lexington. IRE PROCEEDINGS 48: 1380–1395, Aug 1960.

A review of the activities of various governmental, industrial, and academic institutions is made in the field of panel display devices. These devices are thin sheets which can display luminescent information. Insofar as possible the present state of the art is indicated. The displays are grouped as: evacuated, solid, gas, liquid and mechanical. Among the evacuated types are listed the thin cathode ray tubes and the image intensifier. The solid-type displays employ the electroluminescent panel in conjunction with an xy matrix of electrodes. Recent progress in panels of the above type with memory are included as well as a brief discussion of solid-state image intensifiers. Descriptions of proposed gaseous displays as well as of liquid and mechanical displays are included. A brief discussion of switching circuits is included. Actual as well as possible applications of these devices are listed. (Author)

118. Kallmann, Hartmut
Washington Square Coll., New York U., N. Y.
RESEARCH ON SOLID STATE RADIATION-INDUCED PHENOMENA. Quarterly rept. no. 7, 1 Aug–31 Oct 1961. Nov 1961, 34p. (Contract DA 36-039-sc-85126). ASTIA AD-269 907.

Contents: Correlation of light emission and photoconductivity in ZnS phosphors. Preparation of organic mixed crystals by the Bridgman method. Electrophotoluminescence in ZnS, ZnCdS phosphors

119. Karel, F.
The growing of electroluminescent and photoconductive single crystals of zinc sulphide. CZECH. J. PHYS. B11:292, 1961.

The preparation of ZnS single crystals for physical research is described. The conditions for the preparation of luminescent and pure single crystals and the method of activation with copper and manganese are given.

120. Katona, G. P.
Effect of phosphor-embedding medium on performance of electroluminescent cells. ELECTROCHEM SOC-J 109: p. 695-9, Aug 1962.

Effect of dielectrics on brightness and efficiency of electroluminescent cells; increase in dielectric constant of embedding medium above value of 50 does not result in appreciable gain in emission; indications are that maximum efficiency can be obtained when dielectric constant of phosphor and embedding medium are identical.

121. Kazankin, O. N., F. M. Pekermann and L. N. Petoshina.
Electroluminescence of ZnS:Cu:Mn phosphors in a constant field. OPTIKA i SPEKTROSK. (In Russian) 7:776-779, Dec 1959.

ZnS:Cu:Mn phosphors (with 0.05-0.3% Cu and 0-3.0% Mn) prepared in an atmosphere of H_2S + HCl, exhibited strong luminescence in constant (d.c.) fields. The two conditions for d.c. electroluminescence were: (i) the presence of Mn (at least 0.1% was required); and (ii) the presence of Cu as Cu_2S, which raised the electrical conductivity of the phosphor very considerably. The time dependence of the d.c. luminescence was also affected by the amounts of Cu and Mn in the phosphor.

122. Kennedy, E. J., et al.
Rome Air Development Center, Griffiss Air Force Base, N. Y. CRITERIA FOR GROUP DISPLAY CHAINS FOR THE 1962-1965 TIME PERIOD 29p, Jul 1962. (Rept. no. RADC TDR 62-315). ASTIA AD-283 390.

Parameters for a single group display chain that will meet most command and control systems requirements for the 1962-1965 time period are provided. Based on an evaluation as to the best available display state of the art, a film projection system is recommended. Modularity of components is also stressed to derive the benefits of intra and inter-system interchangeability without extensive and costly redesign or retrofit. Basically the display chain will provide: 15 sec updating; six colors plus white; 2400 optical line image resolution; as many as 256 different symbols in up to four different sizes; up to 28,800 symbols generated and displayed in a 120 × 240

format; and line generation for graphics. Discussion is also included on the availability, capabilities and limitations of light valve and electroluminescent techniques for systems application. (Author)

123. Keyes, R. J. and T. M. Quist
Radiation Emitted by Gallium Arsenide Diodes.
Paper presented at Solid-State Device Research
Conference, Durham, New Hampshire, 9–11 Jul
1962. (Proceedings to be published)

When appropriately diffused GaAs diodes are biased in the forward direction at 77°K, nearly all of the injected carriers, upon recombination, emit a photon whose energy is slightly but significantly smaller than the optically measured band-gap of GaAs ($n \simeq 6 \times 10^{16} cm^{-3}$) from which the diodes were fabricated was found to have a long wavelength tail which extends to approximately 1.43 ev. The intense peak emission appears in the spectral region of this absorption tail. At room temperature two peaks are observed - a broad peak at 1.0 ev and a narrow (0.05-ev wide) peak at 1.35 ev.

When the temperature of the diode is lowered to 77°K the broad emission peak at 1.0 ev nearly disappears, a small new peak appears at 1.28 ev and the narrow peak shifts to 1.45 ev, increasing greatly in intensity and narrowing to 0.017 ev. A weak but measurable amount of emission is found to extend into the visible portion of the spectrum. It was a first thought that this weak visible light was the source of the "red glow" which emanates from the diode at low temperature; however, recent observations of the "red glow" through a GaAs filter and a monochrometer prove that the "red light" is really due to the excitation of the retina by the intense peak at 1.45 ev.

To demonstrate the communications potentiality of these diodes, both audio and video signals have been transmitted by so modulating the infrared output. This output has been transmitted a distance of 275 feet where it was received at a photomultiplier, detected and the video or audio amplified and suitably displayed. The rebroadcast signal was of the same high quality as the initially received signals. The gallium arsenide diode infrared source should make possible the early realization of many of the communication applications recently proposed for the optical maser.

124. Kikuchi, M. and S. Iizima
Avalanche electroluminescence in CdS single
crystal. J. PHYS. SOC. JAPAN 14:852, Jun
1959

Electroluminescence observed in forward biased CdS diodes is discussed. The diodes are constructed with rectifying silver paste electrode and an ohmic evaporated In

layer. A linear relationship was found between the current through the cell and the light intensity. As the voltage was increased to a critical value between 25 and 50 v, the current increased rapidly and light was emitted from the periphery of the junction. It is believed that avalanche breakdown occurs in the bulk of the crystal at the critical forward voltage and the light emission is due to the recombination of the electrons and holes generated by the avalanche process.

125. Kikuchi, M. and T. Iizuka
Observation of microplasma pulses and electroluminescence in gallium phosphide single crystal.
J. PHYS. SOC. (Japan) 15:935, May 1960.

With a W contact to a GaP single crystal, microplasma pulses were obtained over a range of reverse bias voltages. Electroluminescence emission occurred below the point contact.

126. Kolomoitsev, F. L and E. V. Stauer
Effect of the copper concentration on the optical and electrical properties of ZnS:Cu. UKRAYIN.
FIZ. ZH. (USSR), (In Ukrainian) 6:781–5, 1961.

With an increase of the copper concentration, the conductivity changes little at first, but at concentrations at which copper no longer dissolves in the ZnS lattice the conductivity sharply increases by 5-6 orders. At these concentrations of copper there is an increase in the dielectric permittivity of the powder phosphor and an increase in the electroluminescence intensity. In the phosphors that contain, besides a poorly conducting phase of the phosphor itself, an additional, well-conducting phase in the form of ZnO and Cu_2S , the dielectric permittivity depends acutely on the frequency. As the copper concentration increases in the phosphor, the photodielectric effect and the conductivity are decreased. On wetting a good ZnS:Cu photoluminophor with a copper salt solution, the dried phosphor produces a weak green electroluminescence. With subsequent calcination of the phosphor in an H_2S atmosphere the green electroluminescence vanishes, and at temperatures when the copper begins to enter into the ZnS lattice a blue electroluminescene appears. Calcination in an HCl atmosphere furthers the appearance of green electroluminescence.

127. Kotera, Y. and K. Naraoka
The Gudden–Pohl effect of ZnS:Cu.
J. ELECTROCHEM. SOC 106:1066, Dec 1959.

Measurement of the Gudden–Pohl effect and thermoluminescence of ZnS:Cu showed that in the cubic phase, the effect decreased with increasing temperature between 20° and 120°C, and no glow peak occurred in this range, while in hexagonal ZnS the effect had a maximum at 70°C, and a glow peak occurred at 55°C.

128. Kozina, G.S., V.N. Favorin and I.D. Anisimova
Luminance (brightness) waves of electroluminescence
under the conditions of simultaneous action of
D.C. and A.C. fields. OPTIKA I SPEKTROSK
8:218–223, Feb 1960. (In Russian)

Green (ZnS:Cu) and yellow (ZnS:Cu:Mn) phosphors were excited simultaneously with a.c. and d.c. voltages. The a.c. voltages were either square pulses of 100 c/s sinusoids. Distortions of the luminance waves observed in the yellow phosphors were due to superposition of the non-additive effects of d.c. and a.c. fields. No distortions of the liminance waves were observed in the green phosphors on simultaneous application of a.c. and d.c. fields.

129. Kozina, G. S. and L. P. Poskacheeva
Total luminance of luminescence of ZnS:Cu
and ZnS:Cu:Mn phosphors in pulsating fields.
OPTIKA I SPEKTROSK 8:214–217, Feb 1960.
(In Russian)

Reports measurements of the total luminance of electroluminescence of green (ZnS:Cu) and yellow (ZnS:Cu:Mn) phosphors. Luminance of the yellow phosphors in pulsating fields (B_p) was found to be several times greater than their luminance in two-directional (ordinary a.c.) fields (B_{ac}), and these high values of B_p were accompanied by large currents through the samples. The difference between B_p and B_{ac} was considerably reduced with rise of frequency. Luminance of the green phosphors in pulsating fields was slightly smaller than in two-directional fields. The difference between the behavior of the yellow and green phosphors is due to the fact that the former luminesce in d.c. fields and are consequently affected by the d.c. component of the pulsating field.

130. Kremheller, A.
Microscopic observations of electro-luminescent phosphors. J. ELECTROCHEM. SOC. 107:8-12, Jan 1960.

The electroluminescent brightness of single phosphor particles is studied microscopically in liquid dielectric cells. Visual technique in conjunction with a microscope permits one to analyze the brightness distribution within and among electroluminescent particles. Some results are presented on the nonuniformity of the emission, the influence of ball milling and acid etching on the brightness, the improvement of brightness by particle separation, the analysis of the integrated light output as a function of the processing temperature, and the brightness changes due to particle orientation, contact, and irradiation.

131. Krumme, J. B. and W. J. Leivo
INVESTIGATION OF SEMICONDUCTING PROPERTIES OF TYPE IIb DIAMONDS.
Oklahoma State U. Research Foundation, Stillwater, Tech. rept. on Luminescence in Semiconducting Diamond. Jan 1961. 37p.
[Contract AF 18(603)40] (AFOSR-272).
ASTIA AD-252 995.

None of the investigated semiconducting diamonds is found to exhibit fluorescence. Exciting wavelengths used are 364 Millimicron which excites fluorescence in type I diamond and 225 Millimicron which is sufficiently energetic to excite carriers across the forbidden energy gap. The temperature dependence of intensity and decay lifetime of the slow decay luminescence indicate that this process is phosphorescence rather than slow fluorescence. Not intensity peaks are found in the phosphorescence spectrum to correspond with photoconductive or photovoltaic peaks, nor is it possible to correlate the decay lifetime of phosphorescence with carrier lifetimes. A red phosphorescence was found during the investigation and observations are included. Each of the investigated specimens exhibits triboluminescence. Electroluminescence is found to correspond to carrier injection rather than intrinsic electroluminescence. Inhomogeneity of surface states which was observed in early studies of photovoltaic effect are also observed in the study of electroluminescence.

132. Krumme, J. B. and W. J. Leivo
Luminescence in semiconducting diamond.
BULL. AM. PHYS. SOC., Ser. II.
5:187, 21 Mar 1960.

Investigation of various forms of luminescence in semiconducting diamond, conducted to correlate the results with other known properties of the same specimens, was reported. Ultraviolet-light-induced blue luminescence was observed in the investigated temperature range of 90° to 430°K, and the spectrum extended from 375 mμ to 615 mμ with a maximum at 480 mμ at 300°K. The temperature dependence of the luminescent intensity indicated that the luminescence is a phosphorescence rather than a slow fluorescence. One specimen had a blue region and a clear region, and in the former the luminescence was considerably more intense, the electrical conductivity much higher and the photoconductive response different from that in the clear region. Both regions are p-type semiconductors. Electroluminescence and triboluminescence were observed in all specimens. An unusual red luminescence with a longer lifetime than the blue luminescence was found in two of the samples. The red luminescent intensity which is quite low at room temperature increased with increasing temperature, being already quite apparent at 360°K and thus implying a phosphorescent process.

133. Kuchar, K.
Remarks on the theory of electroluminescence
in ZnS crystals. CZECH. J. PHYS. 9:679–684,
1959. (In German)

Electroluminescence is assumed to depend on tunneling of electrons through a semiconductor layer on the crystal surface and their subsequent recombination with empty activator centers during the applied voltage cycle. Comparison of theory and experimental results is made for the dependence of emission on applied field strength and frequency and on temperature.

134. Larach, S. and R. E. Shrader
ELECTROLUMINESCENT DEVICES.
(Assigned to RCA) U.S. Patent 2,921,218.
12 Jan 1960.

Devices which utilize the electroluminescence of boron nitride to produce ultraviolet radiation and several colors in the visible spectrum are described. The ultraviolet radiation is produced by applying an alternating voltage across a cell consisting of finely divided boron nitride dispersed in a light transmitting dielectric medium between

a metallic electrode and a transparent, electrically conductive electrode. Several colors are produced by applying an alternating voltage across a similar device which has either an additional layer consisting of an ultraviolet-excitable phosphor or one layer in which the phosphor and the boron nitride are both mixed together and dispersed in the dielectric medium. Phosphors which can be utilized to produce white, red, blue, green, or yellow light are listed.

135. Larach, S. and R. E. Shrader
Electroluminescence of polycrystallites.
R.C.A. REV. 20:532–563, Dec 1959.

The important aspects of luminescence and of electroluminescence are discussed, including incandescence, differences between electroluminescence and other types of luminescence, designing electroluminescent materials to emit in any desired (visible) spectral range, nature of the energy-absorbing layer, and various electrical and optical aspects of the electroluminescence from polycrystallites.

136. Larach, S.
POLYCHROMATIC ELECTROLUMINESCENT
MEANS. (Assigned to RCA) U.S. Patent 2,925,532.
16 Feb 1960.

An electroluminescent color television screen is described. Red-, green-, and blue-emitting phosphors are placed in a dielectric in close proximity to each other. These are then energized in a particular sequence by the application of an electric field between transverse electrodes, at least one of which is transparent, on either side of the dielectric. Some phosphors used in this application are also listed.

137. Lehmann, W.
AREA-TYPE LIGHT SOURCE. (Assigned to
Westinghouse) U.S. Patent 2,924,732. 9 Feb 1960.

Electroluminescent cells which can emit radiation in a particular wavelength range even though the electroluminescent phosphors utilized do not produce radiation of that wavelength are described. This is made possible by the use of fluorescent materials which fluoresce in the desired wavelength region when irradiated by the primary electroluminescent radiation. Either one or two fluorescent materials can be employed in a particular cell. For example, red radiation can be produced by utilizing blue-emitting copper-activated zinc sulfide and the fluorescent materials, naphtacene and pentacen, the former having an absorption peak in the violet-blue region and an emission peak in the green, and the latter having an absorption peak in the green and emission in the red.

138. Lehmann, W.
Microscopic observations on electroluminescent ZnS:Cu phosphors. J. ELECTROCHEM. SOC. 107:657–658, Jul 1960.

Microscopic observations on electroluminescent ZnS:Cu phosphor particles are discussed. The particles were stuck in a thin plastic layer between two aluminum electrodes evaporated onto a microscope slide and the space between the particles was filled with a highly refracting liquid. Dark segregations of copper sulfide (probably Cu_2S) were observed inside many particles. The segregations were generally thin and elongated. Electroluminescence was observed directly at the ends of the segregations in many cases. Emission which could not be correlated to segregations was observed and in some cases segregations which did not emit emission were observed. Light emission per spot was found to occur only once per cycle of the exciting voltage. The linear dimensions of the segregations approach 5 to 10 per cent of the particle diameter in ordinary phosphor powders. The emitting spots have the same dimensions. The brightness of a single spot does not steadily decrease with time. Irregular fluctuations of the light have been observed.

139. Lehmann, W.
Voltage dependence and particle size distribution of electroluminescent phosphors. J. ELECTROCHEM. SOC. 107:20–26, Jan 1960.

The particle sizes of electroluminescent ZnS phosphors prepared by common firing techniques usually range over broad distributions which always have the same shape. Every phosphor of this "normal" particle size distribution shows a voltage (V) dependence of electroluminescent brightness (L) which, over many decades of L, can closely be described by

$$L = L_0 \exp\left[-(V_0/V)^{0.5}\right].$$

Every deviation of the particle size distribution from the "normal" form also causes a deviation of the measurable L(V) dependence from this expression. Measurement on phosphor particles and on uniform phosphor films indicate that the basic excitation mechanism of electroluminescence follows the voltage dependence

$$L = L_0 \exp\left[-(V_0/V)\right]$$

and that the square root in the exponent of the usual equation is due mainly to the broad particle size distribution of regular phosphors. This view is supported also by a mathematical analysis.

140. Lendvai, E., J. Shanda and Ya. Veisburg
Some remarks on the d.c. and a.c. electroluminescence of ZnS:Cu:Mn. ACTA PHYS. HUNGAR. 13:183–192, 1961. (In Russian)

Analyzing the results of Favorin et al, the authors come to the conclusion that the alterations observed in the spectrum can be explained by the local heating due to the d.c. component of the a.c.-d.c. electroluminescence appearing simultaneously in the cells and by the thermal quenching effect found in the green light. In the second case the spectra are not voltage- but heat-dependent, the temperature dependences of the bands differing from each other.

140a. Lewis, Charles W.
ELECTROLUMINESCENT LAMP STRUCTURES.
(Assigned to Westinghouse Electric Copr.)
U.S. Patent 3,018,402. Applied 6 May 1957.
23 Jan 1962.

This patent is a follow-on to an earlier Westinghouse patent (U.S. 2,920,256.) EL lamp structures have been made of transparent or translucent dielectric material plus a suitable phosphor placed between two conductors across which a voltage is applied. Cyanoethyl cellulose is used as the dielectric material.

141. Lewowski, T.
Excitation of photostimulated co-exoelectron emission by anodic oxidation of aluminum.
Z. NATURFORSCH. 15a:90–91, Jan 1960.
(In German)

An attempt to determine whether exo-electron emission is associated with the electroluminescence during anodic oxidation is made. Direct and alternating currents were used in electrolysis and luminescence observed at the anode. After washing and cold drying, stimulation of exo-electron emission was obtained after a.c. electrolysis but not after d.c. electrolysis.

142. Litton, C. W. and D. C. Reynolds
Edge emission in CdS crystals that show mechanically excited emission. PHYS. REV. 125:516–523, 15 Jan 1962.

The characteristic green fluorescence of CdS single crystals that exhibit mechanically excited emission was examined spectroscopically at 4.2° and 77°K. The fluorescence of the crystals was stimulated by either ultraviolet irradiation, or the application of an electric field. The u.v.-stimulated and field-induced emission spectra are compared and discussed. The low-temperature behavior of the conductivity (storage properties) in these crystals is also discussed. The u.v.-stimulated edge emission peaks in these crystals differ from those in normal CdS; these differences are discussed and quantitative comparisons are made. A simple trapping model is applied to the u.v.-stimulated emission data at 77°K. On the basis of this model, the mean number of optical phonons cooperating in the optical transitions is shown to be higher than in normal CdS. The field emissi on, believed to be due to carrier injection, is explained on the basis of a previously proposed energy model of Warschauer and Reynolds for mechanically excited emission.

143. Litvinova, P.S., L.R. Rabotkina and P. E. Ramazanov
Investigation of the initial stages in the onset of electroluminescence of a ZnS:Cu:Al phosphor. OPTICS AND SPECTROSC (USA) 11:139–140, Aug 1961.

Electroluminescent cells without binder, excited at 400 c/s showed the main peak of light output to rise to a steady maximum after about 10 cycles of applied voltage, while the phase-shift of light relative to voltage changed similarly. With temperature change the steady light peak at 10 cycles exhibited minima near -140° and -5°C, and a maximum near 60°C. The phase-shift changed similarly with temperature except that there was no low temperature minimum.

144. Loebner, E. E.
Solid-state optoelectronics. R.C.A. REV.
20:715–743, Dec 1959.

Discusses the uses of photoelectric and luminescent phenomena. A description is given of optico-electronic modulators and amplifiers, i.e. devices which have mixed optical and electrical signal and power access. The technology of assembling image-transmitting, image-storing, and picture-reproducing panels from optico-electronic elements is reviewed. The function of various optico-electronic logic nets and computer components is treated in detail. A synthesis of panel technology and logic circuitry into novel picture-processing panels and computer systems is proposed. The similarity between the organizational structure of such parallel processing systems and that of the neuron network of vertebrate retinas is pointed out.

145. Lozykowski, H. and H. Meczynska
An attempt to obtain electroluminescence of organophosphors. BULL. ACAD. POLON. SCI. SER. SCI. MATH. ASTRON. PHYS. (Poland), 9:235–236, 1961.

The same electroluminescence was observed from cellophane colored by organic dyes, and from the uncolored material.

146. Lozykowski, H. and H. Meczynska
Electroluminescence of alkaline earth sulphide phosphors. BULL. ACAD. POLON. SCI. SER. SCI. MATH. ASTRON. PHYS. (Poland), 8:725–728, 1960.

BaS and SrS electroluminophors, each with distinctive emission, were prepared by heating a mixture of $BaCO_3$ or $SrCO_3$ and the activator (Cu, Sn or Ag) in an atmosphere of H_2S. The luminous intensity, B, followed the law $B = A\, e^{-b/\sqrt{V}}$, where V, the applied voltage, was generally larger than the values typical of ZnS and CdS phosphors. The effect on the luminous intensity of variation of the frequency of the electric field between 300 c/s and 5000 c/s was measured for a BaS:Cu electroluminophor. The constant component of the intensity increased almost uniformly with frequency, while the variable component saturated above 1500 c/s.

147. Lozykowski, H.
Electroluminescence of ZnSe:Cu with a Cu_2Se layer in an a.c. and d.c. field.
BULL. ACAD. POLON. SCI. SER. SCI. MATH. ASTRON. PHYS. (Poland)
8:719–724, 1960.

ZnSe:Cu was converted to an electroluminophor by the addition of a thin coating of Cu_2Se. Electroluminescence was investigated with sinusoidal voltages 0 to 400 V at frequencies between 100 and 15000 c/s and with pulsed and d.c. voltages. The luminescence from a suspension of the phosphor in castor oil was red for a.c. fields and shifted to shorter wavelengths with d.c. The brightness waveform was dependent on the frequency of the a.c. The relation of the current through the cell to the applied field strength was in agreement with the theory of thermal-electric ionization. The phosphor was also dispersed in paraffin wax. A yellow luminescence was obtained, and the cell acted as a current rectifier. At sufficiently large forward bias, the luminescent intensity was proportional to the current through the cell. It is suggested that this may be explained by impact excitation of the centers in strong-field regions of the phosphor.

148. Lozykowski, H and M. Rozwadowski
The influence of ultrasonics on the electroluminescence of ZnS:Cu. BULL. ACAD. POLON. SCI. SER. SCI. MATH. ASTRON. PHYS. (Poland) 7:651–652, 1959.

Observations were made of the effect of ultrasonic vibrations of frequency 0.68 Mc/s on the brightness waveform of the electroluminescence stimulated in ZnS:Cu (0.5% by weight Cu) by sinusoidal fields of frequency 0.2 to 5 kc/s. Specimen results are presented. The effects cannot be ascribed to temperature variations.

149. Lyamichev, I. Ya., et al.
Experimental investigation of the possibility of realizing multiple component electroluminescent devices employing ferroelectric materials. BULL. ACAD. SCI. USSR PHYS. SER. (USA) 25:487–493, 1961.

The use of a series-connected ferroelectric capacitor of triglycine sulphate and an electroluminescent cell is considered in various circuits for the display and erasure of images. Operation at 5-15 kc/s is best, but a large voltage control signal is needed to give images of sufficient contrast. Pulses require much lower voltages for the same effect. Hysteresis occurs in the ferroelectric response. Light amplifiers of very high gain at low input brightness can be made if the photoconductor detector is in a d.c. loop while the ferroelectric and electroluminescent cell are under a.c.

150. Lyamichev, I. Ya., and I. N. Orlov
The effect of electrical pre-history of an electroluminescent phosphor on the characteristics of its emission when excited with short voltage pulses. OPTIKA I SPEKTROSK. 7:398–406, Sep 1959. (In Russian)

ZnS:Cu(Pb,Cl) and ZnS:Cu:Cl phosphors were excited with square voltage-pulses from a special generator which produces several independently controlled series of pulses. Each pulse produced a light pulse consisting of two peaks. The mechanism of formation of these peaks is discussed in terms of electrical pre-history; in the case of pulse excitation such pre-history means the duration, period, amplitude etc. of pulses up to a given moment.

151. Maeda, K.
Electroluminescence of insulated particles. II
J. PHYS. SOC. JAPAN 15:2051–2053, Nov 1960.

Lehmann's experimental results on the emission intensity of a single electroluminescent phosphor particle embedded in an insulating dielectric as a function of the applied voltage are analyzed on the model proposed in Part I. The local field enhancement is attributed to the disturbance of the applied field due to the conducting phase of the phosphor particle. The results are reasonable and the validity of the model is confirmed.

152. Maeda, K.
Origin of local high electric field in electroluminescence. PHYSICA. 25:721–722, Aug 1959.

Zalm's model for electroluminescence, in which the phosphor grains are completely covered by a conducting layer, is not in agreement with experiment, in particular because of the lack of excitation when the short axis of a grain is parallel to the applied field. It is considered that excitation occurs at the edge of discontinuous conducting layers on the grains.

153. Maruyama, E.
Luminescence accompanied by electrolysis in CdS single crystals. J. PHYS. SOC. JAPAN 16:2341–2342, Nov 1961.

Luminescence observed at the crystal-electrolyte interface of a 10^{-1} ohm-cm CdS:Cl crystal immersed in an electrolyte such as KBr, NaI, KCl, or NaH_2PO_4 is disucssed. The emission occurs when the crystal is positively biased with respect to the electrolyte. At an applied voltage of 20–25 v, a negative resistance region occurs and the current rises rapidly. The breakdown is accompanied by an orange luminescence. Spectral observation indicated that the luminescence has a broadband around 600 mμ and a spectral distribution which depends on the anion in the electrolyte. In the negative resistance region, the emission intensity is voltage dependent. As a result, it is concluded that the emission is due to electroluminescence in the crystals. After several seconds, a layer of sulfur atoms forms on the face of the crystal and the luminescence ceases.

154. Mash, D. H.
An electroluminescent digital indicator with a silicon carbide coding matrix. J. SCI. INSTRUM. 37:47–50, Feb 1960.

A digital indicator is described using an electroluminescent panel having its back electrode shaped as an array of lines, from combinations of which the digits are formed. Also describes is a coding matrix which greatly simplifies the electrical switching needed for the indicator. The coding matrix utilizes the non-linear electrical properties of silicon carbide powder to discriminate between the voltage applied to wanted elements and unwanted elements, and allows a single-pole ten-way switch to be used for selecting the required digit.

155. Matossi, F., H. Gutjahr and D. Siebert
Capacitance growth and electrophotoluminescence
of an optically excited ZnCdS phosphor under
the effect of a direct electric pulse.
Z. NATURFORSCH. 16a:1391–1393, Dec 1961.
(In German)

The capacitance change during application of an electric field pulse was measured to investigate changes in electron concentration in the volume of crystal grains. The capacitance change occurs immediately when the field is switched on and then decays. When the pulse is lengthened a further similar sharp change in capacity occurs as the field pulse switches off. Light emission also shows a second pulse at the latter point not observed for short pulses where switch-off causes a quenching of emission.

156. Matossi, F. and G. Schmid
Electroluminescence in zinc sulphide single
crystals. Z. PHYS. 166:455–459, 1962.
(In German)

Luminescence observed at the anode of ZnS crystals on excitation with a.c. voltage, with and without superimposed d.c. voltage, shows "green" maxima (5200 A) at phases related to the phases of zero voltage or current. They disappear if the electrodes are isolated from the crystal. The observations can be interpreted by assuming hole injection as the cause of the electroluminescence and taking into account a decrease of recombination probability with increasing velocity of the charge carriers. At high voltages, a "blue" maximum (4770 A) appears in phase with voltage maximum, over the whole crystal.

157. Matsuo, T.
Preparation of electroluminescent zinc
sulfide phosphor. KOGYO KAGAKU
ZASSHI 65:1735–1739, 1962. (In Japanese)

158. Meyer, L. C.
AN ELECTROLUMINESCENT TRANSDUCER.
Sandia Corp., Albuquerque, New Mexico.
Rept. no. SCTM-326-59(2). 28 Aug 1959.
44p.

A study was made to determine some of the characteristics of electroluminescence and the feasibility of using electroluminescent transducers for converting electrical timing signals to an optical image.

159. Mohrbach, Paul F. and Robert F. Wood
DEVELOPMENT OF BRAOD-BAND ELECTRO-MAGNETIC ABSORBERS FOR ELECTRO-EXPLOSIVE DEVICES. Laboratories for Research and Development, Franklin Inst., Philadelphia, Pa. Monthly progress rept. no. P-B-1857-10, 1-30 Apr 1962. 30 Apr 1962. 42p. (Contract N178-7913) ASTIA AD-278 661.

Effort was applied to improvement of previously demonstrated properties of an electroluminescent-photoconductive (EL-PC) circuit. The terminated power loss ratio is evaluated over the frequency range of 10 kc to 1 mc for an RLC network. Variations in response due to changes in the component values are shown and discussed. A double loop network exhibiting frequency-independent impedance is shown to provide an effective loss of 20 db at 20 kc increasing to 30 db and greater at 35 kc and higher frequencies.

160. Morehead, F. F., Jr.
The mechanism and efficiency of electro-luminescence in ZnS phosphors. J. ELECTROCHEM. SOC. 107:281-287, Apr 1960.

The application of a model of the electroluminescent process to the photon emission and power consumption of insulated electroluminescent phosphors as a function of voltage and frequency is described. The model represents an extension of one described earlier. The model leads to a convenient summary of such data and an increased understanding of their significance. An upper limit to the efficiency of impact electroluminescence in insulated particles is proposed on the basis of the implications of the model.

160A. Morrison, George H. et al.
ELECTROLUMINESCENT PHOSPHORS.
(Assigned to Sylvania Electric Products, Inc.) U.S. Patent 2,999,818. 16 Nov 1959.

(ZnCd)S:Cu phosphors coactivated with Cl and fired with 35-55% by wt. Cu (as $CuSO_4$) at 700−900° result in electroluminescent materials. Excess Cu is removed, and the color of the final product is lightened by entraction with dilute aqueous KCN solution. Thus, a single-component white electroluminescent phosphor is prepared by firing a mixture of 20 g. (Zn (95) Cd (5))S:Cu (0.01-0.03% by wt.) and 17.5 g. $CuSO_4$ for 40 min. at 800° in a covered SiO_2 crucible. This phosphor also shows white fluorescence under ultraviolet radiation.

161. Murray, R. B.
Luminescence in Solids. J. OPT. SOC. AM.
(Oak Ridge Natl. Lab.) 51:808−811, Jul 1961.

A series of papers on the luminescence of solids is reviewed. On the luminescence of alkali halides, articles on heavy metal activated solids are cited. Further papers on luminescence in molecular solids, electroluminescence, some theoretical interpretations, and, finally, application to scintillators are presented. This review covers the period January 1959 through September 1960 for the journal Optics and Spectroscopy.

162. Nagy, E. and J. Weiszburg
Electrical properties of electroluminescent SiC crystals. ACTA PHYS. HUNGAR.
8:235−239, 1957. (In German)

The current-voltage characteristic was observed to follow the theoretical prediction for the reverse current through an exhaustion barrier modified by the image force correction. It also showed an appropriate temperature variation of the current. Deterioration of the surface at the contact, or prolonged exposure of a crystal to air, produced a conducting layer which could be removed by grinding.

163. Nakamura, K., S. Nonogaki, T. Nishimura
Several problems on design of electroluminescence layer. INST ELEC ENGRS JAPAN-J 82(880):70–77, Jan 1962. (In Japanese with English summary)

Measurement results; theoretical equations of relationships between thickness of EL layer and EL brightness; equation of relationships between reflection coefficients of EL electrodes and EL brightnesses; relationships between optical and electrical efficiencies of EL layers and thickness of EL layers; equations of relationships between density of phosphors and EL brightness.

164. Narita, S.
Electroluminescence in zinc sulfide single crystals. J. PHYS. SOC. JAPAN 15:128–136, Jan 1960.

By using the vapor-phase synthesis method, zinc sulphide single crystals were grown of pure zinc and bomb hydrogen sulphide. They were doped with two impurities: copper and chlorine. The electroluminescence brightness waves in these crystals were studied by applying rectangular pulse voltages. Since "in-phase" electroluminescence was dominant in the crystals lacking chlorine and having appreciable voltage-dependency, it was concluded that it occurred as a result of electron injection from the cathode. In order to find the mechanism of the "out-of-phase" electroluminescence, infrared quenching was used. ZnS:Cl:Cu was a typical case sensitive to quenching, and an artifical junction (ZnS:Cl – ZnS:Cu) was a typical case insensitive to quenching. It was supposed that the difference between these two cases resulted from the difference in the mechanism of supply of the primary electrons of electroluminescence.

165. Nehrich, R. B., Jr., and R. K. Logan
A COLOR CONVERSION TECHNIQUE FOR ELECTROLUMINESCENT LIGHT. Navy Electronics Lab., San Diego, Calif. Rept. for period ending Nov 1960. NEL Rept. no. 1121. 6 Jul 1962. 24p. ASTIA AD-278 747.

Efforts were made to develop electroluminescent (EL) lighting for the improvement of reliability and maintainability of systems and instrumentation requiring illuminated

indicators, readouts, or displays. Simple and inexpensive color conversion filters were developed whereby a basic green or blue light can be readily converted to practically any desired color. This technique is capable of producing yellow, orange, or red light, of various shades, that maintains a relatively high level of brightness. It is accomplished at low voltage and frequency, and makes EL illumination acceptable for instrument panels or other applications where blue or green light would be objectionable.

166. Nehrich, R. B., Jr.
ELECTROLUMINESCENT INDICATOR LIGHT. Navy Electronics Lab., San Diego, Calif. Research and development rept. for Jul–Nov 1959. NEL rept. no. 946. 22 Jan 1960. 8p. ASTIA AD-254 538.

An electroluminescent lighting device was developed which can serve as a highly efficient pilot and/or indicator light. Its ease of replacement simplifies the general maintenance of electronic systems; it offers long life and high reliability; and it is adaptable to a variety of applications and mounting techniques.

167. Nehrich, R. B., Jr., and R. K. Logan
MATERIALS RESEARCH IN AND PRACTICAL APPLICATIONS OF ELECTROLUMINESCENCE. Navy Electronics Lab., San Diego, Calif. Research and development rept. for 15 Dec 1958–30 Mar 1960. NEL rept. no. 978. 30 Jun 1960. 13p. ASTIA AD-254 546.

Research was conducted to determine the best techniques and materials for constructing electroluminescent cells for use in military equipments. Several applications were shown to be feasible, including training aids, visual readouts, and various indicators and displays. Considerable improvements were achieved in fabrication methods, including the use of copper-clad epoxy Fiberglas boards for the substrate layer of the cell.

168. Neumark, G.
Efficiency of electroluminescence in ZnS.
PHYS. REV. 116:1425-1432, 15 Dec 1959.

The efficiency is examined on the basis of a model of impact ionization in a barrier. On the basis of such a model, the efficiency depends on the ionization rate, and this rate is calculated by applying to ZnS a theory developed for Ge and Si. By considering the voltage dependence of the efficiency one can then get an estimate of a maximum obtainable efficiency in terms of the ratio of the barrier voltage to the total voltage. Both on the basis of this maximum efficiency and from other considerations it appears that the present theory can account for the magnitude of efficiencies reported to date.

169. Nicoll, F. H., A. Sussman, and H. B. Devore
ELECTROLUMINESCENCE IN OPTICAL AMPLIFIERS. Radio Corp. of America, Princeton, N.J. Final rept. for 1 Mar 1958-30 Nov 1959 on Research on the Quantum Nature of Light. Dec 1959. 82p. [Contract AF 33(616)5509, Proj. 7072]. (WADD TR 60-147). ASTIA AD-259 630.

Work done in two broad areas is summarized. The first is work directed specifically towards the fabrication of a prototype light amplifier having a two-color input and a two-color output; the second is work on materials which might eventually be of value in light amplifiers. The work which leads directly to the two-color light amplifier is described along with that work which was rejected for the final prototype. The final method, using two photoconductors on the input, is covered in more detail. A full description of the construction of a 6 x 6-in. panel is given and the exact formulation of the various layers appears in the Appendix. Results are given for the two prototype panels to be delivered under the contract and the means of testing and demonstrating the panels is described. A section of the report is devoted to a description of the mounting and testing equipment for these panels. The second area of work covered in the report is on materials. This includes measurements on cadmium sulfide and cadmium selenide photoconductive powders.

170. Nicoll, F. H.
Solid state image intensifiers. In NASA.
Proceedings of the [Second] Image Intensifier
Symposium, Ft. Belvoir, Va., 24-26 Oct 1961.
p.9-18. NASA Report N62-14876.

The paper discusses the combination of electroluminescent layers with photoconductive layers to form imaging panels. The properties of presently available photoconductors in combination with the wellknown a.c.-operated electroluminescent layers have not been fully exploited in image intensifiers or storage panels. Improved photoconductors alone would increase performance of the panels, but it has also been clear for some time that an improvement in efficiency of the conventional electroluminescent layer alone would immediately provide improved performance. Still greater improvement would be realized if the electroluminescent layer were d.c. operated. This is because the sensitive photoconductors operate better in d.c. Altogether there is every reason to believe that solid-state image intensifiers will improve considerably as the research on light sensitive and light emissive materials continues. As the panels improve they should become competitive with photoelectric image intensifiers in more than the very few special applications where this is now the case.

171. Nudelman, S. and J. Mudar
Fatigue in electroluminescent phosphors.
BULL. AM. PHYS. SOC., Ser. 11.
5:70, 27 Jan 1960.

Observations of fatigue in electroluminescent phosphor panels (decrease of electroluminescence under constant operating conditions) at frequencies up to 6 mc, with applied voltages up to 1500 v across a 4-mil thick cell, were reported. Fatigue is accelerated with increasing frequency, so that at 2 mc, electroluminescence diminishes from 10 to 25 percent of initial values within 30 minutes. Fatigued phosphors show a decrease in time average light output at the higher frequencies. Mechanically shaking a phosphor-air electroluminescent cell after fatigue causes a partial restimulation of electroluminescence, followed by fatigue. Successive shakes show a decreasing effect, corresponding to all sides of the phosphor particle being fatigued. This indicates a uniform filling of deep surface traps, or a uniform degradation in electroluminescent centers. Tests for deep traps using high voltage, low frequency fields simultaneously with photo-stimulation were negative. Measurements on phosphor in air and in various dielectrics indicate with Roberts that fatigue is characteristic of the phosphor although his law has not been confirmed. Appreciable fatigue occurs for cells operated down to liquid nitrogen temperatures.

172. O'Connell, J. A.
Electroluminescent-photoconductive patern recognizer organizes itself. ELECTRONICS 34:54–57, 14 Jul 1961.

A sandwich module using flow table principles to recognize a 12-bit digital word is described. The device consists of a recognition panel, a storage panel and an input panel. The digital input is divided into four 3-bit words which are applied to successive recognition gates where they are compared with a pattern optically coupled-in from the storage panel. An ON condition is shifted from stage to stage when the digital information presented to the stage matches a pattern of binary words that it has been programmed to accept. Different recognition patterns are obtained by altering the pattern of illuminated controlling photoconductors in the flow table panel. Under single-shot operation, speeds of 3-4 msec per logical decision have been obtained. Under continuous operation, the speed is 5–10 times slower per decision element because of the slow photoconductor decay time.

173. Oranovskii, V. E. and B. A. Khmelinin
Investigation of electroluminescence of ZnS:Cu monocrystals. OPTIKA I SPEKTROSK. 7:542–546, Oct 1959. (In Russian)

Properties of long, narrow regions, known as "dashes", in electroluminescent ZnS:Cu monocrystals were studied. Observations of brightness waves from various sectors of a "dash" and studies of the effect of an ultraviolet light spot on these waves showed that excitation and emission processes occur throughout each "dash". Sectors of a "dash" are regions of p- or n-type conductivity. It was also found that electroluminescence can be produced by field intensities not greater than 10^4 V/cm.

174. Oranovskii, V. E. and Z. A. Trapeznikova
Investigation of the electroluminescence and photoluminescence spectra of phosphors activated with rare-earth elements. OPTIKA I SPEKTROSK. 5:302–306, 1958. (In Russian. English summary: PB 141047T-7, obtainable from Office of Technical Services; U.S. Dept. of Commerce, Washington, D. C.)

Phosphors studied: ZnS:Er,Cu; ZnS:Nd,Cu; ZnS:Er,Cu,Mn; with 4.6×10^{-4} gram-atoms/mole of Cu, 2.3×10^{-4} gram-atoms/mole of Er or Nd, and 4.3×10^{-3} gram-atoms/mole of Mn. The presence of Mn produced a strong band characteristic of Mn, a major increase in brightness of Er emission, and the appearance of the red lines of Tm (impurity in Er). Electroluminescence and photoluminescence spectra were measured under similar conditions. It is concluded that the centers responsible for the two types of emission are the same, and are similarly distributed throughout the lattice; that the emission is mainly due to low-energy "thermal" electrons; and the effective volume active in electroluminescence is about 7% of the volume active in photoluminescence.

175. Oranovskii, V. E.
Investigation of the electroluminescence of zinc sulfide single crystals. BULL. ACAD. SCI. USSR, PHYS. SER. 25:512–513, 1961.

Electroluminescent striations in a single crystal of ZnS:Cu,Cl were examined microscopically with an ultraviolet probe of 0.1 mm diameter directed along the different axes. When parallel to the striations the maximum + and - differences were observed between the light distribution (a) with field only, and (b) with field and ultraviolet. In ZnS:Cu,Mn the striations were red or blue according to the local activator, the red (Mn) ones being less affected by ultraviolet than were the blue (Cu) ones. It is concluded that processes of field concentration are independent of additional injected charge carriers.

176. Oranovskii, V. E. and B. A. Khmelinin
Study of electroluminescence of ZnS-Cu single crystals. In PHYSICS AND CHEMISTRY OF CRYSTALLINE PHOSPHORS, by H. Ortman and H. Witzman. Berlin, Akademic Verlag, 1960. p.112–116. (In German)

Properties of luminous "streaks" in electroluminescent crystals of ZnS-Cu were studied. Observation of the change of the brightness waves in different regions under ultraviolet irradiation showed that excitation and emission take place over the whole extent of the "streak". Each region has its characteristics brightness wave, which differs from that of neighboring regions. It is suggested that this is associated with p-type and n-type conductivity regions.

177. Palilla, F. C. and D. H. Baird
Red emitting (zinc, cadmium) (sulfide, selenide) electroluminescent phosphors. J. ELECTROCHEM. SOC. 109:1162–1166, 1962.

Red electroluminescence at 60 cps has been obtained with copper-activated, bromine co-activated, $Zn_{1-x}Cd_xS_{1-y}Se_y$ systems at field strengths as low as 50 v/mil. Emission color depends on the Cd and/or Se contents. Electroluminescence sensitivity depends on crystal structure. The ratio of host lattice components, together with the conditions of firing, etablishes the crystallographic nature of the matrix. The results suggest a similarity to the structural features associated with optimum electroluminescence in ZnS. Details of phosphor preparation and performance are discussed.

178. Patek, K.
The electroluminescence of ZnS-Cu single crystals excited with pulses of alternating polarity. CZECH. J. PHYS. 10B:452–467, 1960.

The brightness waves of electroluminescence of ZnS-Cu have been measured for the case of excitation with rectangular pulses as a function of the amplitude of the pulses and the temperature. A concrete model is proposed for electronic processes in barriers in ZnS crystals, the consequences of which for the decay of electroluminescence are in agreement with measurements.

179. Patek, K.
On the electroluminescence of ZnS at low voltages. CZECH. J. PHYS. 11B:18–20, 1961.

The possibility of explaining non-zero electroluminescence brightness below the minimum ionization voltage by the influence of thermal velocities of electrons is discussed. The derived voltage dependence of electroluminescence brightness agrees with previously reported measurement.

180. Patek, K.
On the photo-electroluminescence of ZnS-Cu. CZECH. J. PHYS. 9:161–167, 1959.

The influence of weak u.v. irradiation on the brightness waves of electroluminescence is investigated for two types of ZnS:Cu phosphor. The observed effects (increase in brightness in the primary peak and its phase shift, are the disappearance of the secondary peak) are explained on the basis of current accepted electroluminescence models.

181. Patek, K.
Temperature dependence of secondary peak of electroluminescence of ZnS-Cu. CZECH. J. PHYS. 9:460–467, 1959.

The temperature and frequency dependences of the secondary peak of the brightness wave were studied. The dependences found show a direct connection with the number and depth of the traps. The influence of a continuously increasing temperature on the secondary peak of electroluminescence of a sample, which has been irradiated beforehand, is found and a description given of a new method of determining trap depths and their number.

182. Peka, G. P. and Yu. I. Karkhanin
The dependence of luminescence of cuprous oxide on external electric field. DOKL. AKAD. NAUK SSR 141(1):63–65, Nov 1961. (In Russian)

A dependence of infrared luminescence on external electric fields of 10^4 -6 x 10^5 V/cm applied perpendicularly to the surface was observed. The specimens were illuminated with light of 435.8 and 491.8 mμ wavelengths; the relative change in the luminescence brightness was higher at 735 mμ. The time dependence of the luminescence changes varied with the polarity of the applied field, intensity of the exciting light and surface conditions. The influence of the electric field on the curvature of energy bands at the surface is believed to explain the effect.

183. Pettsol'd, E. G.
Some electroluminescent properties of $ZnO-Bi_2O_3$ mixtures. IZV. AKAD. NAUK SSSR, SER. FIZ. 24(1):104–112, 1960. (In Russian)

Constant voltages were applied to compacted powder mixtures of n-type ZnO and p-type Bi_2O_3. Yellow or blue electroluminescence was observed near the electrodes. Studies of electroluminescence and current as a function of the applied field and time (decay) showed that the observed effects were related to the formation of space charge.

183A. Piper, William W.
LONG-LIVED ELECTROLUMINESCENT CELLS. (Assigned to General Electric Co.) German Patent 1,083,428 (class 21f) 11 Apr 1959. (U.S. patent applied for 28 Apr 1958). (In German)

Electroluminescent panels are formed by fusing EL materials with low-melting glass, grinding, and embedding them in a resin. One part zinc sulfide (0.3% copper) is

ground to 10μ size with 2 parts of a glass containing the following:

B_2O_3	29.2
Sb_2O_3	20
Si O2	20
ZnO	17
NaO_2	5
NaF	7.8
Al_2O_3	2

After being fused at 530° the powder is reground to 50μ size. Then it is embedded in an epoxy or cyanoethyl cellulose resin which results in a cell retaining 91% of its original brightness after 800 hours of use.

184. Rabotkin, V. L. and V. A. Sokolov "Anisotropy" of a luminance wave from a polarized electroluminescent cell. OPTIKA I SPEKTROSK 8:276–277, Feb 1960. (In Russian)

A polarized electroluminescent cell was prepared by solidifying a suspension of ZnS: Cu: Pb in molten paraffin wax between two electrodes with 2000 V d.c. across them. The cell was excited with periodic unipolar pulses. If the polarity of the pulses coincided with the polarity of the field used to prepare the cell, then the luminance (brightness) wave had two approximately equal peaks in each period. When the pulse polarity was opposite to that of the field used to prepare the cell, the second of the luminance peaks became narrower and higher than the first. This effect was observed both in a freshly prepared cell and several days after its preparation.

185. Rabotkin, V. L. and V. A. Sokolov Investigation of the electroluminescence of some phosphors with excitation by unipolar pulses. BULL. ACAD. SCI. USSR PHYS. SER (USA) 25:520–522, 1961.

The light pulses from ZnS:Mn and ZnS:Cu:Pb phosphors excited by unipolar sine pulses of electric field were investigated.

186. Rabotkin, V. L.
Electroluminescence of zinc sulfide-copper, lead microcrystals. OPTIKA I SPEKTROSKOPIYA 12:601-603, 1962. (In Russian)

187. Ranby, P. W. and P. J. Clemer
Current applications of electroluminescence. TRANS. ILLUM. ENG. SOC. 25:267-280, 1960.

The construction of electroluminescent lamps using ceramic enamelling techniques is described and their properties are compared with the electroluminescent lamp which employs organic dielectric materials. These "ceramic" lamps lend themselves to applications where a low brightness source of robust construction is required together with long life, for example, instrument lighting as in automobile dashboards, electric clocks, and telephone dials. The "organic" lamp is already used for aircraft signs, but digital indicators and other indicator panels can be constructed. The "organic" type can also be combined with photoconductance materials to provide a number of interesting devices such as "optrons" and image intensifiers and converters, and the X-ray image converter is a particularly promising application. Some new phosphors which show a marked d-c electroluminescence when used in ceramic constructions are described.

188. Ratner, M.
Ionic properties of electroluminescent zinc sulfide. BULL. AM. PHYS. SOC. (Ser. 11) 5:70, 27 Jan 1960.

By the use of a photographic technique, simultaneous measurements of the instantaneous capacity and conductivity as functions of temperature (T), the maximum value of the applied voltage (V_m), and the frequency (f) have been made on dielectric cells of electroluminescent ZnS:Cu:Cl. This material behaves like a highly ionic semiconductor. The conductivity (σ) follows the high-field ionic relationship: $\sigma = [\, N (ea)^2 \nu/kT \times \exp(-E/kT)] \cosh \{ (ae/2lkT) V_m \sin(2\pi ft)\}$, where N is the concentration of lattice defects, a is the jump distance, ν is the characteristic lattice frequency, e is the electronic charge, and l is the effective thickness of the cell. Experimentally found values are in agreement with those determined by other investigators: $\sigma \sim 10^{-9}$ ohm^{-1} cm^{-1}; $N \sim 10^{17}$ per cm^3, $\nu = 7 \times 10^7$ cps; E = 0.28 ev; $a = 2 \times 10^{-6}$ cm. The energy of the defects is $\sim$5kT at high fields for these cells. Dielectric relaxation

peaks are present at 1.5 and 30 kc, and in the neighborhood of 1−10 cps. The low-frequency peak is ascribed to the action of ultra-violet light, and the 1.5-kc peak is associated with the emission of green light. The mechanism responsible for the 30-kc peak has not been identified.

189. Rebane, K. S.
The steady-state luminescence of ZnS phosphors. II. Electroluminescence and infrared quenching. OPTICS AND SPECTROSC. (USA) 12:217−218, Mar 1962.

Steady-state luminescence, electroluminescence, and the infrared quenching of electroluminescence and photoluminescence were investigated from the point of view of the zone model. The results are compared with experiment.

189A. Reschauer, Egbert
LUMINESCENT SCREENS. German Patent 1,106,600. Class 57b. Applied 19 Sep 1958. (In German)

This patent is a follow-on to an earlier German patent, 1,032,088. Reflection layers for electroluminescent screens are made by coating luminescent screens with an aqueous solution of synthetic resins containing such gels as alginates, proteins, or pectins fixed by gelling and solidified by water evaporation.

190. Rhyzkov, V. A. and B. T. Fedyushin
Temperature dependence of the electroluminescence of zinc sulfide-copper, chloride single crystals. OPTIKA I SPEKTROSKOPIYA 13:721−723, 1962. (In Russian)

191. Roeppischer, H.
Influence of infrared-irradiation on the electro-photoluminescence of ZnCdS-Mn phosphors.
WISS. Z. HOCHSCH. ELEKTROTECH.
ILMENAU 7:125-128, 1961. (In German)

The luminescence of Mn-activated ZnCdS phosphors may be enhanced by increasing infrared irradiation as well as ordinary ac. By suitable combination of the two methods conclusion may be reached on "memory-effects" of the system.

192. Rose, A. and R. H. Bube
The role of space-charge currents in light amplifiers. R.C.A. REV. 20:648-657, Dec 1959.

The light-gain, the operating input light level and the exposure for single pictures are derived for light amplifiers of the sandwich type using adjacent layers of photoconductor and electroluminescent material. A key parameter in these relations is the voltage V_m at which space-charge current flow is initiated in the photoconductor. Also involved is a factor M which measures the ratio of recombination centers to traps, both evaluated near the Fermi level. Present photoconductors should permit: (a) light-gains of over 100-fold to be achieved at television frame rates; (b) operation at television frame rates with input light intensities as low as 10^{-1} lm/ft^2; and (c) exposures for single pictures approaching photographic speeds. Improved performance depends strongly on attaining higher values of M photoconductors.

193. Item deleted.

194. Rutherford, R. E., Jr.
RESEARCH AND INVESTIGATION ON
PHOSPHOR SCREENS FOR HIGH RESOLUTION
DISPLAY DEVICES. CBS Labs., Stamford, Conn.
Interim engineering rept. no. 1, 12 Jun–31 Aug 1961.
(Rept. no. 114) 23 Oct 1961. 4p. [Contract
AF 33(616)8509] ASTIA AD-265 105.

Research and investigation has been undertaken leading to the development of phosphor screens for high resolution display devices. The program is limited to the development of material processing and screen generation techniques using available materials. The general objective is to develop the techniques of using available materials to generate a luminescent screen capable of transferring information at a rate equivalent to a bandwidth of 15 mc with S/N of 30 db and with a peak radiant intensity sufficient to expose high resolution film through a high quality optical system of f:4. Phosphor screens were prepared to provide a basis of comparison for the development work. Methods used to deposit coatings of P16 phosphor, CaMg(Si04):Ce included spraying using a volatile vehicle, settled from a liquid suspension and electrodeposited from a liquid suspension.

195. Rutherford, R. E., Jr.
RESEARCH AND INVESTIGATION ON
PHOSPHOR SCREENS FOR HIGH RESOLUTION
DISPLAY DEVICES. CBS Labs., Stamford, Conn.
Interim engineering rept. no. 2, 1 Sep–31 Dec 1961.
23 Jan 1962. 4p. [Contract AF 33(616)8509]
ASTIA AD-269 880

Research and investigation on phosphor screens to improve their information transfer capacity continued. Improvements in phosphor screen formation by the electrodeposition technique were studied. Preliminary results on the measurement of the dynamic range of phosphor screen performance are indicated.

196. Sack, E. A., P. N. Wolfe, and J. A. Asars
Construction and performance on an elf display system. PROC. IRE 50:432–441, Apr 1962.

An experimental display system featuring a solid-state display screen is described. The system includes a 256 cell-per-square-inch electroluminescent panel, row and column drivers for the panel distribution matrix, and character generation equipment to form target images on the display in accordance with a computer word input. The brightness pattern on the 4- by 8-inch panel is controlled and stored by a ferroelectric micro-array. A matrix of gaseous discharge elements called ionic switches distributes the control signals to the ferroelectric structure. Less than 2 per cent of the 8192 cells of the completed panel are faulty. Highlight brightness is 2.8 foot-lamberts and contrast is 25:1, both figures are below design objectives due to limits set on panel excitation for this model. It is concluded that better mechanical design and improved quality control during fabrication should approximately double the performance characteristics of the system.

197. Schultz, G.
Electroluminescent layers produced by evaporation. MONATSBER. DEUTSCHEN AKAD. WISS. BERLIN. 3:81–82, 1961. (In German)

Thin layers of copper-activated ZnS were produced by vacuum-evaporation of ZnS powder and luminescence was observed under excitation with an alternating voltage of 20 c/s to 15 kc/s.

198. Schwager, E. A.
On the electroluminescence of ZnS-ZnO melts. Z. PHYS. 163(1):44–55, 1961. (In German)

ZnS, ZnO, $PbCO_3$ and CuO fused at 1900°C under N_2 pressure produce hexagonal polycrystalline material, whereas ZnS alone becomes cubic. Compared with normal sulfides these melts show the same photoluminescence except for the relative amplitudes of different bands, and the glow curves are similar. Electroluminescence from a solid plate of the material is similar to that from a 1100°C preparation. Observations are recorded on the temperature dependence of electroluminescence, on the light waves and the effect of infrared on them. There seems to be no voltage threshold in electroluminescence.

199. Services Electronics Research Lab. (Gt. Brit.)
S.E.R.L. TECHNICAL JOURNAL. VOLUME 12,
NO. 1. Feb 1962. 85p. ASTIA AD 275-632.

Contents:
Semiconductor counters
The electrical properties of n-type gallium arsenide
Injection electroluminescence at P-N junctions in zinc-doped gallium phosphide
Some properties of copper-doped gallium phosphide
Spin waves in ferromagnetic metals
Gallium phosphide diodes for the production of fast light pulses

200. Shapiro, I. P. and N. I. Kuznetsov
Effect of ultraviolet irradiation on the luminescence characteristics of an electro-luminophor. BULL. ACAD. SCI. USSR, PHYS. SER (USA) 25:519-520, 1961.

At -20°C the total luminescence in a liquid dielectric cell of ZnS:Cu under a combined a.c. field and (d.c.) ultraviolet is less than the sum of the electroluminescence and the photoluminescence separately. At 50°C the total luminescence is greater than the sum. Frequency effects are discussed.

201. Siddall, G.
The preparation of electroluminescent panels.
VACUUM 7-8:61-71, 1957-1958. Publ. Apr 1959.

Gives complete details of the manufacture of electroluminescent light sources, using vacuum deposited films for the conducting electrodes. Commencing with a glass base, which is made electrically conductive by sputtering a transparent cadmium oxide film, the phosphor is mixed with a resin-based lacquer and sprayed on the semiconducting oxide film. This is followed by a second layer of insulating material upon which the top electrode of aluminium may be deposited by evaporation in vacuum. Upon applying an alternating field between the two conducting electrodes, the phosphor emits light through the transparent oxide film. Three power supplies have been made to supply alternating current at suitable voltage and frequency, and full details are given.

202. Siekmeir, D.
AN APPARATUS FOR THE REAL-TIME TRANSMISSION OF HANDWRITING AND MAP INFORMATION TO REMOTE DISPLAYS.
Institute of Science and Tech. U. of Michigan, Ann Arbor. Memo on Proj. Michigan.
Rept. no. 2900-300-R. Jan 1962. 29p.
(Contract DA 36-039-sc-78801) ASTIA AD 269-991.

A breadboard model of a photoelectrically operated device which quickly determines the coordinates of any point on a map was developed. Its essential components are a manually positioned light source and two servo-controlled light-sensitive follower units, one for each axis. The follower units automatically position themselves in accordance with the coordinates of the light source and generate analog voltages corresponding to these coordinates. These voltages may be used to actuate a digital device to give a direct readout of the coordinates of the light source, or, if the operator traces a line or curve with the light source, the path thus traced may be reproduced at a remote location on an X-Y plotter whose inputs are connected to the coordinate outputs of the follower units.

203. Smith, D. H.
Electroluminescence – its characteristics and applications. ELECTRONIC ENGRG.
33:68–72, Feb 1961, 33:164–170, Mar 1961.

The characteristics of the light emitted from electroluminescent cells energized by sine waves, square waves, and pulses of voltage are described, the mechanism of electroluminescence is discussed, and some of the many applications are reviewed. Examples cited include electroluminescent cells used as light sources and for the visual display of information, and light amplifiers made from a combination of electroluminescent and photconductive elements. The possibility that an array of very small electroluminescent cells could be used as a thin-screen television display is cited.

204. Sorkin, F. V., A. P. Belyaeva and N. S. Borodin
Use of electroluminescence for character indicators. BULL. ACAD. SCI. USSR, PHYS. SER (USA) 25:523-525, 1961.

The design and performance of electroluminescent indicators, which display numbers or letters, is described.

205. Soxman, E. J.
ARMY/NAVY INSTRUMENTATION PROGRAM. PART II. ELECTROLUMINESCENT THIN FILMS. Servomechanisms, Inc., Goleta, Calif. Summary rept. pt. 2, for 1961. Rept. no. SMIR 62-3. 1961. 22p. ASTIA AD 272-929.

A procedure was developed for producing an electroluminescent thin film of Mn activated ZnS by a one-step process of coevaporation of a mixture of ZnS and Mn metal powder. GeO2 was a satisfactory dielectric layer compatible with the phosphor. Evaporated Al and Mo were satisfactory for the top electrodes. Mo offered an optical advantage in that a film which was semitransparent in the visible range could be used. A d.c. bias superimposed on a pulsed signal was observed first to decrease the emission intensity of the thin film electroluminescence, then after a certain threshold value had been reached to increase the emission intensity through an ac-dc enhancement effect.

206. Stauer, E. V. and V. P. Izotov
Dielectric and optical properties of zinc sulphide materials. IZV. AKAD. NAUK SSSR SER. FIZ. 24:224-228, 242-245, 1960. (In Russian)

Complex permittivity of electroluminescent and nonelectroluminescent ZnS powders was studied as a function of the intensity and frequency of the applied field, temperature and surface treatment. The temperature dependence of the intensity and spectrum of electroluminescence was also investigated. Some of the observed effects are related to conducting ZnO layers on ZnS powder particles.

207. Stauer, E. V. and M. G. Rozenblat
Effect of pulverization of the optical and
electrical properties of certain ZnS phosphors.
OPTIKA I SPEKTROSK 7:570–571, Oct 1959.
(In Russian)

Pulverization of ZnS:Cu, ZnS:Cu:Al, ZnS:Cu:Mn and other phosphors reduced the intensity of both photoluminescence and electroluminescence, produced displacement of the electroluminescence spectrum towards longer wavelengths and fall of the temperatures at which quenching of electroluminescence began. After pulverization the real and imaginary parts of complex permittivity decreased, dependences on the applied-field frequency and intensity and on temperature became less pronounced, the dark and photoconductivities decreased and the ratio of photoconductivity to dark conductivity fell. All these changes are due to the change in the particle dimensions and due to the effect of deformations produced during grinding.

208. Stauer, E. V.
Electroluminescence of barium titanate at
audio frequencies. BULL. ACAD. SCI. USSR,
PHYS. SER. (USA) 24:1347–1349, 1960.

The effects were measured of temperature and of variations in the frequency of the exciting a.c. field upon the strength of the electroluminescence of ceramic barium titanate. Continuous electroluminescence stimulated by d.c. fields was observed to be several orders of magnitude weaker than a.c. stimulated emission. The strength of the a.c. stimulated emission was reduced in the presence of a d.c. biasing field up to a certain saturation value of the d.c. field strength, and was also reduced by compression of the sample in the direction of the stimulating field. The d.c. stimulated emission was found to be time-dependent. Under a.c. stimulation, the emission occurred preferentially near to the positively biased electrode. An explanatory model is suggested involving field emission of electrons from the cathode (or field ionization of shallow traps near to the cathode) and the subsequent return of these carriers to the same region when the direction of the applied field is reversed. The free electrons are then assumed to recombine with the holes, possible via impurity levels. Variation of dielectric constant caused by variations in the temperature, applied pressure, or biasing field produces changes in the current flow through the specimen which is thought to explain the comparable electroluminescence features observed under these conditions.

209. Steinberger, I. T., V. Bar, and E. Alexander
Electroluminescence of zinc sulfide single crystals. PHYS. REV. 121:118–124, 1 Jan 1961.

The results of a series of experiments designed to distinguish between ionization and recombination processes during electroluminescence in which rectangular voltage pulses were applied to single crystals of zinc sulfide are reported. During the "on" period, the emission gradually increased to a stationary level. Removal of the voltage resulted in a burst of emission, which decayed slowly. This behavior is explained by the assumption of three field-dependent processes, namely: (a) ionization of centers in barrier regions; (b) sweeping out of the liberated electrons from the vicinity of the centers; (c) tunnelling of electrons into the barrier regions. It was found that for a considerable voltage range the product of the light-sum (measured during the "off" period) by the current was proportional to the stationary emission level during the "on" period. This proportionality strongly supports the model suggested. In many cases the current was found to be more strongly dependent on the voltage than the light sum. This result favors an ionization mechanism which is independent of the current. The model suggests furthermore an alternative explanation for the Neumark-effect, i.e., the enhancement of the thermal glow by electric fields. The explanation does not involve an impact-ionization mechanism.

210. Stewart, R. D.
Solid-state optoelectronic commutator.
ELECTRONICS 35:38–39, 16 Feb 1962.

A solid-state commutator using electroluminescent-photoconductive cells is described. The device provides microvolt region sensitivity and is linear over a wide range of signal levels. The commutator consists of an array of photoconductive switches. An eight-channel commutator consisting of a T-section switch connected to a conventional binary tree was constructed using CdS photoconductors and orange electroluminescent cells. The lit resistance of the photoconductors was 800 ohms and the dark resistance 300 kilohms. Switching times were in the 50–200 msec range. The noise of four series-illuminated photoconductors was less than 12 μv for a 2 Mc bandwidth.

211. Szepesi, Z.
Photoconductor-electroluminescent display panels on fotoform glass. In 1962 INTERNATIONAL SOLID-STATE CIRCUITS CONFERENCE DIGEST OF TECHNICAL PAPERS. N.Y., Lewis Winner, 1962. p.86-87.

Describes the basic circuit consisting of the series connection of a photoconductor (PC) and an electroluminescent (EL) element for display panels. A simple sandwich construction does not yield satisfactory characteristics. Among the suggested new designs is the fotoform glass plate, promising several advantages, in particular the possibility of separation of the PC and EL layers so that PC elements with lateral electrodes can be used leading to a better impedance relation. Opaque fotoform glass can be used for image intensifiers and white fotoform glass with a lattice of opaque lines for storage display panels. Both have been built by Westinghouse, employing an evaporated CdS and a plastic embedded ZnS layer. A resolution of 16 elements/in has been realised as well as a luminous gain of 170 (max). The different fabrication steps are also explained. By different sensitizing processes photolayers with sublinear and superlinear current-light intensity characteristics have been prepared on fotoform substrate. Characteristics of the EL layers with different slopes have been achieved. With improved technique in fotoform glass manufacture, it is possible to build low-resolution display panels. The paper includes illustrative sketches, photographs and curves.

212. Tanaka, S.
Electroluminescence of ZnS phosphors excited by short field pulses. J. PHYS. SOC. JAPAN 14:1123-1140, Sep 1959.

Electroluminescence in ZnS:Cu, Pb phosphors was investigated. Excitation and recombination mechanisms of luminescent centers are discussed. Rectangular pulses were used having durations of from 1 to 40 μsec. From the experimental results of emission spectra, brightness waveforms, dependences of light outputs on the applied voltages and pulse durations, decay times, build-up characteristics and their temperature dependences, it is concluded that the local intense field generated at the cathode region of phosphor particles accelerates the primary electrons and the luminescent centers are impact-ionized by these electrons. The field strength may be smaller than in the case of sinusoidal field excitation and then the excitation efficiency of the primary electron greatly decreases compared with the latter case. The primary electrons are partly generated thermally and partly by the direct field-ionization. The

electroluminescence decay obeys the bimolecular law and is affected by the electron traps in the region of long pulse durations. The build-up characteristics are also affected by the deep-lying electron traps.

213. Tarjan, P. P.
AN INVESTIGATION OF THE VACUUM EVAPORATION TECHNIQUES OF ELECTROLUMINESCENT PHOSPHORS. Electronic Systems Lab., Mass. Inst. of Tech., Cambridge. Rept. no. 7848-7849-TM-9. Oct 1960. 134p. [Contracts AF 33(616)5489 and AF 33(616)5477, Projs. 7848 and 7849] ASTIA AD 247-433.

The possibility of using thin electroluminescent films in the fabrication of electro-optical devices inspired the investigation of the vacuum deposition of such films. A survey of the literature indicated the possibility of obtaining power amplification in electroluminescent phosphor films subjected to both electric field and ultraviolet light excitation. Vacuum deposition offers the possibility of fabricating very thin, transparent films of intricate geometrical shape. Vacuum evaporation and deposition of phosphors poses a number of problems. In order to be electroluminescent, the film must have the proper amount of impurity atoms in the proper crystalline structure. Thus, each part of the vacuum process must be examined for its affect on the final composition of the film and its crystalline structure. Commercially available phosphor powders were evaporated by various techniques. The most successful involved heating the phosphors slowly from a radiant source. Only this type of evaporation resulted in even faintly electroluminescent films. Some work was done on the fabrication of transparent conducting electrodes which set up the electric field in phosphor films. Bismuth oxide base layers coated with pure gold, while soft, seemed satisfactory. In general, the investigation showed encouraging signs for the construction of electroluminescent films by vacuum evaporation.

214. Thomsen, S. M.
An electrical analog for electroluminescent layers. RCA REV. 22:685–697, Dec 1961.

An analog for EL (electroluminescent) layers which can be devised using only capacitors and neon glow lamps is discussed. This suggests that a "breakdown" current, limited by capacitive impedance, flows in each light-emitting flow spot. This current is presumably delivered within the EL phosphor particle from internal electrodes formed during the phosphor synthesis. The deterioration of brightness during the operating life of an EL layer can be attributed to the electrical erosion of the internal electrodes.

215. Thornton, W. A.
Direct current electroluminescence at low voltages. PHYS. REV. 122(1):58–59, 1 Apr 1961.

Electroluminescence due to d.c. excitation occurs in activated ZnS films at 2.0 V. Since in the d.c. case no ambiguity is introduced by possible transient potential differences within the phosphor layer, these experiments show that electroluminescence can occur at applied voltages corresponding to about half the band gap (3.8 eV) of the ZnS phosphor. The acceleration-collision theory of electroluminescence is thus ruled out at low voltage, and since no appreciable difference is found to be characteristic of the electroluminescence at low voltages, the acceleration-collision mechanism may not be important in any voltage range.

216. Thornton, W. A.
Electroluminescence at low voltages. PHYS. REV. 116:893–894, 15 Nov 1959.

Electroluminescence occurs in activated ZnS thin films at 1.5 V r.m.s. (peak voltages 2.2 V) corresponding to electron energies less than the band gap (3.8 eV) and less than the mean energy (2.6 eV) of the photons emitted. The light emission decreases by 10^4 between 2.0 and 1.5 V r.m.s. and shows no tendency toward a threshold, nor does its spectral character change at low voltage. This behavior suggests that electroluminescence does not depend upon collision ionization but perhaps on carrier injection or free electron temperature.

217. Thornton, W. A.
Electroluminescence of thin ZnS films. BULL. AM. PHYS. SOC., SER II. 6:266, 24 Apr 1961.

The ac electroluminescence of thin ZnS:Cu, Cl films was compared with that of powder phosphors. The major difference was found to be that strong asymmetry in the films causes light emission only during the half-cycle of the applied voltage when the transparent tin oxide electrode upon which the film is formed is negative. The other (aluminum) electrode plays no part since an intermediate insulating layer has no effect. The resistive current component in the films is, however, symmetrical with voltage polarity, as are both light and current in powder phosphors; this implies that the electrodes are never involved and that current and light emission are controlled by internal junctions in both phosphor films and powders. Direct current, as well as instantaneous ac current (resistive) in these films is proportional to $[\exp(V/V')-1]$, where V' is a constant. If either voltage half-cycle is clipped (or eliminated) by a

rectifier, the light emission is reduced (or eliminated). Direct voltage bias, added to the alternating voltage, has the same effect although in this case the rms voltage is constant; the effect of the sign of the dc bias voltage indicates that the ionization process occurs during one half-cycle (with no light emission) and that the resulting light emission occurs on the following half-cycle.

218. Thornton, W. A.
Electroluminescence in zinc sulfide as due
to minority carrier injection. J. ELECTROCHEM.
SOC. 108:636–645, Jul 1961.

Under the proper experimental conditions which can be fulfilled in conventional electroluminescent ZnS powder dispersions in dielectric material or in luminescent films, the restive component of the a.c. current follows the diode equation (for forward bias)

$$I = I'[\exp(V/V') - 1],$$

where v is the applied r.m.s. voltage. The parameter I' is proportional to exp(-E/kT) and V' is proportional to temperature and phosphor layer thickness. Three independent determinations give the number of active forward-biased junctions per micron of ZnS phosphor as about 15. The forward currents are shown to be directly related to electroluminescence emission and are compared directly to a.c. currents in Ge p-n junctions. Irradiation effects on the conductance of a phosphor layer and a Ge photojunction are compared. D.C. electroluminescence in ZnS at 2.0 V is also cited against the acceleration-collision theory, and the major arguments in its favor are discounted.

219. Thornton, W. A.
Electroluminescence maintenance. J.
ELECTROCHEM. SOC. 107:895–907,
Nov 1960.

The maintenance of several electroluminescent phosphors, mainly of the ZnS:Cu,Cl type, was investigated. Data are presented illustrating its dependence on phosphor properties, such as copper and chlorine additions, firing temperature and particle size, on conditions of operation, and on lamp construction. Changes in properties other than light emission and recent maintenance improvements are described.

220. Thornton, W. A.
Thin-film elucidation of the electro-luminescence process. PHYS. REV. 123:1583–1586, 1 Sep 1961.

Very thin sulphide films emit light only on alternate half-cycles of the voltage sine wave, whereas the emission of thicker films and phosphor powders is quite symmetrical with polarity. This asymmetry of emission, together with clipping or d.c. bias of the applied voltage, is used to confirm unambiguously that the excitation and recombination steps in electroluminescence are separable and occur sequentially and under different field configurations, and that the recombination is field-driven.

221. Ting, Szu-Yun
Effect of the size of phosphor crystals on the yield or electroluminescence. WU LI HSUEH PAO 17(2):99–103, 1961. (In Chinese)

The yield of electroluminescence was studied by observation of the mechanism of impact ionization with consideration of dependence of probability of recombination on energy of free electrons. The yield as a function of voltage was measured. The interpretation of obtained results is given: the height of the peak (max.) of the curve of the function increased with decreased size of phosphor crystals, while the peak of the curve, characterizing dependence of yield of electroluminescence on the voltage, applied between 2 ends of crystal, is displaced to the side of the lower voltage.

222. Trimble, P. K.
ELECTROLUMINESCENCE: A SELECTED BIBLIOGRAPHY. Electronic Components Lab., Wright Air Development Center, Wright-Patterson Air Force Base, Ohio. Rept. on Improved Electronic Components. Apr 1959. 15p. (WADC Technical note no. 59-110). ASTIA AD-213 601.

A selection is presented of current bibliographic references on the subject of electroluminescence. The references chosen cover the full range of information on electroluminescence from the theoretical aspects to practical applications. Since the subject is a fairly recent discovery, this bibliography consists entirely of articles from periodicals and reports. A useful feature is the breakdown of the information on electroluminescence into the various subjects or aspects. The subjects are then cross-indexed with the references.

223. Trofimov, V. S.
The dependence of the brightness of electroluminescence on voltage. OPTIKA I SPEKTROSK. 4:113–115, Jan 1958.
(In Russian. English summary PB 141047T3, obtainable from Office of Technical Services, U.S. Dept. of Commerce, Washington, D.C.).

The 50 c/s electroluminescence of ZnS:Cu was studied in a special cell accommodating a single layer of $\sim 5\ \mu$ crystals. This enabled the actual field in the crystals to be determined in the region where brightness varied as exp $(-1/V)$, V being the applied voltage. Electroluminescence was observed with actual fields as low as 5×10^4 V/cm, suggesting that impact ionization can set in long before breakdown of the crystal, and that localized exhaustion regions are unnecessary.

224. Uehara, Y., et al.
Lead- and manganese-activated calcium cadmium silicate phosphors. J. ELECTROCHEM. SOC. 108:235, Mar 1961.

The preparation and properties of (Pb + Mn)-activated calcium cadmium silicate phosphors with various mole ratios of Cd to Ca are described. All phosphors produce a main, broad and variable emission band in the orange, and three minor, narrow and invariant bands at about 6880, 6950, and 7050A. The phosphors show a complicated shift of the main emission band with increasing Cd content, despite a linear relationship between Cd content and lattice spacings. The introduction of sulfate ions into the phosphor base changes the emission characteristics. With half of the Ca introduced as sulfate, the peak emission shifts from 6100 to 6200 A. The results are discussed in the light shifts from 6100 to 6200 A. The results are discussed in the light of several assumptions.

225. Ullman, F. G.
Electroluminescence of gallium phosphide crystals. NATURE 190:161–162, 8 Apr 1961.

Single crystals of GaP were grown from solutions of P in Ga. Electroluminescence emission spectra were obtained at -100°C and room temperature. In undoped crystals peaks occurred at 5700A and 6500A, and in crystals containing Zn a peak occurred at 7000A. Crystals with more than 0.01% Zn did not luminesce.

226. Vereshchagin, I. K.
Ageing of ZnS phosphors. OPTICS AND
SPECTROSC. (USA) 9:270–271, Oct 1960.

The electroluminescence and photoluminescence spectra of ZnS and ZnS-CdS phosphors, containing silver and large amounts of copper, were compared immediately after preparation and after 1-3 years' storage. The short-wavelength band in photoluminescence (characteristic of non-activated and Ag-activated phosphors) was intensified by storage. The band due to copper was either weakened or remained unaffected by storage. The photoluminescence spectrum of stored phosphors approached the form of the electroluminescence spectrum. The effects of long storage could be removed entirely by heating above 200°C for 20–30 min. The changes on ageing were due to changes in the amount of free sulfur in the phosphors: CuS or Ag_2S formed slowly in the phosphors at room temperature.

227. Vereshchagin, I. K.
Electroluminescence and surface properties
of crystal phosphors. BULL. ACAD. SCI.
USSR, PHYS. SER (USA) 25:514–515, 1961.

A brief description is given of the effects of adsorbed gases on the electroluminescence, photoluminescence and photovoltaic behavior of ZnO.

228. Vereshchagin, I. K.
The effect of adsorption of gases on electro-
luminescence. OPTIKA I SPEKTROSK.
8:420–421, Mar 1960. (In Russian)

Electroluminescence of ZnO was affected by the ambient medium (air or vacuum) and ultraviolet radiation. The observed effects are interpreted in terms of oxygen adsorption and desorption.

229. Vereshchagin, I. K. and I. T. Drapak
Electroluminescence of single crystals of ZnO. OPTICS AND SPECTROSC. (USA) 12:61, Jan 1962.

Reports experimental results obtained with a.c. and d.c. excitation. In the former, maximum emission occurred at about 2-4 kc/s, while the dependence on the applied voltage was similar to that for ZnS. Under d.c., there was a very rapid increase in the intensity when the applied voltage was increased from about 110 V to about 120 V (Ga contacts).

230. Vereshchagin, I. K.
On the relation between the luminescent, electrical and chemical properties of zinc oxide. IZV. VYSSHIKH UCHEBN. ZAVEDENII. FIZ. 2:31-36, 1960. (In Russian).

Measurements of the intensity of electro- and photoluminescence, the electrical conductivity and the concentration of excess zinc in ZnO samples, roasted at 100° - 200°C under different conditions are discussed. On the basis of the existence of a relation between all the investigated quantities as well as between the magnitude of the catalytic activity and the brightness of the electroluminescence, the possibility of the participation of a double electrical layer on the surface, formed as a result of adsorption of the gas molecules, in the process of exciting electroluminescence is considered. Certain deductions are made on the electroluminescence mechanism in ZnO.

231. Vinokurov, L. A. and M. V. Fok
The simultaneous action of light and electric fields on phosphors. OPTIKA I SPEKTROSK. 7:241-243, Aug. 1959. (In Russian)

The effects of light and electric fields were found to be nonadditive: in some cases the luminescence due to simultaneous excitation was higher and in other cases it was lower than the sum of the brightnesses of both types of luminescence. In two ZnS:Cu, Al phosphors the maximum observed non-additivity amounted to about 10%. The authors show that the exact additivity can be obtained with A/B = const., where A and B are the number of acts of ionization of luminescence centers per unit volume and per unit time due to light and due to electric field respectively.

232. Vlasenko, N. A.
The effect of temperature on electro-luminescence of a sublimated phosphor ZnS:Mn. OPTIKA I SPEKTROSK. 8:414-417, Mar. 1960. (In Russian)

Reports studies of the thermoluminescence and temperature dependences between 100 and 500°K of electroluminescence, photoluminescence and electrical conductivity. The sharp rise of electroluminescence and the fall of photoluminescence above 300°K are explained in terms of donor-level kinetics.

233. Vlasenko, N. A. and Uy. A. Popkov
Investigation of electroluminescence of the sublimated ZnS:Mn phosphor. OPTIKA I SPEKTROSK. 8:81-88, Jan 1960. (In Russian)

Pure zinc sulphide and manganese were evaporated simultaneously in vacuum onto glass plates and the resultant layers were heat-treated at 500-550°C in order to diffuse Mn into ZnS and to produce good crystal structure. The layers exhibited intrinsic electroluminescence which was a bulk property, and not a surface effect. The intensity of electroluminescence of these layers rose more sharply with the applied field than the intensity of powder phosphors. Shallow (~ 0.1 eV) donor levels were found in the layers. The ionization energy of these levels depended on applied voltage, indicating electric field-aided thermal ionization. The electroluminescence spectrum of the layers was a simple band of 0.20 eV half-width with a maximum at 2.13 eV (582 mμ).

234. Wachtel, A.
CaS:Cu,Eu electroluminescent phosphors. J. ELECTROCHEM. SOC. 107:199-206, Mar. 1960.

Introduction of Cu into CaS:Eu does not interfere with the red Eu^{++} emission. Excitation of the blue CaS:Cu emission is more effective by 3650 A than by 2537 A. Firing with excess Cu gives rise to deposits of free Cu_2S which may cause an efficient system of contact electroluminescence. The electroluminescent properties depend on the physical characteristics of the phosphors, including its state of agglomeration. At moderate concentrations of Eu, the blue emission of CaS:Cu is entirely suppressed in electroluminescent excitation.

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235. Wachtel, A.
(Zn, Hg)S and (Zn, Cd, Hg)S electroluminescent phosphors. J. ELECTROCHEM. SOC. 107:682–688, Aug. 1960.

The preparation of cubic structure solid solutions of (Zn, Hg)S by firing in sealed silica tubes is reported. With suitable additions of Cu and a coactivator, photoluminescence and electroluminescence are obtained. The coactivators used were halides, Ga, or In. The red electroluminescence consists of two emission bands which do not appear to be analogous to the blue and green emission bands of Cu, Cl in ZnS. The quantum efficiency is of the same order of magnitude as that of ZnS:Cu, Cl, but the emission bandwidth is about twice as large and the red electroluminescence consists of emission located to a large extent in the infrared. HgS tends to retain the cubic structure of ternary (Zn, Cd, Hg)S systems provided that the Cd/Hg ratio does not exceed certain limits. The introduction of Cd causes increased electroluminescence until these limits are attained.

236. Wachtel, A.
ZnS:Cu, Cl and (Zn, Cd)S:Cu, Cl electroluminescent phosphors. J. ELECTROCHEM. SOC. 107:602–608, Jul 1960.

Procedures for a method of preparation of these phosphors are based on firing in an atmosphere containing elementary S. Cl-incorporation is controlled by firing in capped silica tubes or in open boats in a current of $N_2 + S_2Cl_2$. Dependence of brightness on activator concentration is established on the basis of presumably constant excess Cu as Cu_2S. The use of Pb was found to be disadvantageous. Introduction of Cd causes the formation of the hexagonal phase and a (Cu, Cd)S compound, and the simultaneous decrease of electroluminescence brightness, as well as the dependence of electroluminescence emission color on Cd concentration. A two-step firing procedure is given by means of which this effect may be partially avoided.

237. Wachtel, A.
(Zn, Hg)S and (Zn, Cd, Hg)S electroluminescent phosphors. J. ELECTROCHEM. SOC. 107:682–688, Aug. 1960

Solid solutions of (Zn, Hg)S prepared by firing in sealed silica tubes are discussed. The crystals are cubic in structure. With suitable additions of Cu and a coactivator, e.g. halides, Ga, or In, photoluminescence and electroluminescence are obtained. The electroluminescence in the red consists of two emission bands which do not appear

to be analogous to the blue and green emission bands of Cu, Cl in ZnS. The quantum efficiency is of the same order of magnitude as that of ZnS:Cu, Cl, but the emission bandwidth is about twice as large and the red electroluminescence consists of emission located to a large extent in the infrared. HgS tends to retain the cubic structure of ternary (Zn, Cd, Hg)S systems provided the Cd/Hg ratio does not exceed certain limits; until this is so, the introduction of Cd causes increased electroluminescence.

238. Weiszburg, J.
Electroluminescence at low voltage. ACTA PHYS. HUNGAR. 13:61–66, 1961.

It is usual to distinguish between the intrinsic and the injection electroluminescence, because of the differences of the threshold voltages of their lighting. There is no foundation for this distinction because the orders of the threshold voltages of the two groups agree with each other. The electroluminescent phenomena of evaporated ZnS layers at low voltages can be described also by regularities characteristic of the Mott-Shottky-type barriers. The existing measuring data are not detailed enough to serve as a check of the correctness of the various theoretical hypotheses.

239. Weiszburg, J.
On the electroluminescence of insulated SiC crystals. ACTA. PHYS. HUNGAR. 11:95–96, 1960.

Electroluminescence was observed in crystals of SiC unaccompanied by the usual rectifying effect. The light was emitted when the specimen was separated from one of the electrodes by a mica sheet, requiring an average field of about 10^6 V cm^{-1} a.c. or 20 times the field necessary to produce the same color, distribution and intensity without the mica. This is interpreted as meaning that the electrons causing the light are supplied by surface states rather than by injection from the electrodes, so that SiC electroluminescence can be likened to that of ZnS.

240. Weiszburg, J.
On the grouping of electroluminescent effects. ACTA. PHYS. HUNGAR. 10:337–340, 1959.

The similarities and differences of "carrier injection" electroluminescence and "intrinsic" electroluminescence are discussed in terms of polarity of exciting voltage, rectification, emission spectra, field strength, and several other features. The author finds no very real differences between the phenomena and raises the question of whether a distinction in terminology is justified.

241. Weiszburg, J. and P. Greguss, Jr.
The effect of ultrasonic irradiation on electroluminescent panels. ACTA PHYS. HUNGAR. 11:185–191, 1960.

Electroluminescent panels in an ultrasonic field showed a yellow discoloration, the degree of which depended on the intensity of the ultrasonic field. This effect can be interpreted by the alteration of field strength within the electroluminescent panel due to its local heating.

242. Weiszburg, J., J. Schanda and Z. Bodo
Time-dependent spectra of electroluminescent ZnS:Cu,Pb. PHIL. MAG. 4:830–832, Jul 1959.

The spectra were recorded so that distances along the spectrograph slit corresponded to time variations. By microphotometry of the images, curves were derived showing brightness versus time for several emission wavelengths. There is a negligible phase shift between green and blue bands for 100 c/s excitation, while at 740 c/s the green emission is retarded by not more than 3% of the length of the cycle.

243. Wesolowski, J., M. Jachimowski and R. Dragon
Luminescence in electric fields of "dry" oxide films on aluminum. ACTA PHYS. POLON. 20:303–311, 1961.

The electrical and luminescent properties of electrolytically formed "dry" aluminum oxide films were investigated. Cells consisting of an aluminum base with oxide layer and transparent semiconducting coating were subjected to a d.c. field. The light emission from the oxide layers was observed. The luminescence brightness and cell current were measured against the applied voltage. The properties of dry aluminum oxide films strongly resemble, on the one hand, those of electrolytic cells and, on the other hand, those of typical electroluminescent cells. It is therefore assumed that in either case, the light emission may be considered to represent a process of electroluminescence.

244. Westinghouse Electric Corp., Baltimore, Md.
ELECTROLUMINESCENT FERROELECTRIC (ELF) SOLID STATE DISPLAY. Interim development rept. no. 8. Mar–31 May 1960. 33p. (Contract NObsr-72782) ASTIA AD 246-324.

A study and investigation toward the design and development of a solid state display panel consisting of a multitude of small individual cell structures was conducted. Each cell shall consist of electroluminescent material and ferroelectric non-linear element or structure. The latter shall provide the necessary storage and control function.

245. Westinghouse Electric Corp., Baltimore, Md.
ELECTROLUMINESCENT FERROELECTRIC (ELF) SOLID STATE DISPLAY. Quarterly rept. no. 10. 1 Sep–30 Nov 1960. 13p. (Contract NObsr-72782) ASTIA AD 252-233.

Electroluminescent ZnS phosphor films were prepared for excitation by alternating voltages. Tests of ELF control fins employing W-59 ferroelectric material were continued in order to establish the degree of superiority of that material over the W2-50C ferroelectric employed in the experimental models. A tester was designed to evaluate the non-linear behavior of 1 or more Y (decoupling) capacitors on a ferroelectric insert. Two small screens were made by epoxy-encapsulating a number of standard ferroelectric inserts, following which mosaic electrodes, electroluminescent layers, and transparent electrodes were deposited on the output face of the block. Both screens operated successfully. Consideration was given to the use of a flexible ionic switch back connector and pressure plate for the 4- by 8-in. experimental model ELF display.

246. Westinghouse Electric Corp., Baltimore, Md. ELECTROLUMINESCENT FERROELECTRIC (ELF) SOLID STATE DISPLAY. Quarterly interim development rept. no. 12 for 1 Mar–31 May 1961. 31 May 1961. 10p. (Contract NObsr-72782) ASTIA AD 258-598.

Investigations were continued on the design and development of a solid state display panel consisting of a multitude of small individual cell structures. Brightness and current were measured for several specimens of ZnS:Cu:Cl films at temperatures of 77 K to 330 K. Measurements on all the new ceramic material received to date were completed, utilizing both standard and fringing electrodes.

247. Westinghouse Electric Corp., Baltimore, Md. ELECTROLUMINESCENT FERROELECTRIC (ELF) SOLID STATE DISPLAY. Quarterly interim development rept. no. 13 for 1 Jun–31 Aug 1961. 31 Aug 1961. 8p. (Contract NObsr-72782) ASTIA AD 263-643.

Contents:

248. Westinghouse Electric Corp., Baltimore, Md.
ELECTROLUMINESCENT FERROELECTRIC (ELF) SOLID STATE DISPLAY. Quarterly interim development rept. no. 14 for 1 Sep–31 Nov 1961. 31 Nov 1961. 15p. (Contract NObsr-72782) ASTIA AD 269-602.

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Materials research
Electroluminescence
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249. Westinghouse Electric Corp., Baltimore, Md.
ELECTROLUMINESCENT FERROELECTRIC (ELF) SOLID STATE DISPLAY. Quarterly interim development rept. no. 15 for 1 Dec 1961–28 Feb 1962. 28 Feb 1962. 11p. (Contract NObsr-72782) ASTIA AD 274-630.

Research continued in the fabrication of electroluminescent ferroelectric (ELF) cells. The cells are prepared on aluminum substrates using BaTi03 in polyvinyl chloride with a solids ratio of 24:1 as a barrier layer and VB206P in ME-34 with a solids ratio of 3:2 as the emitting layer. The secret of fabrication of good cells is the proper application of the barrier layer which must be smooth for good leakage characteristics and light output. A number of life tests on cells indicate that an increase in life will result if the screen is operated in a desicated atmosphere. A number of groups of switches were made and a final design was selected. With respect to sandwich structure, the first sandwich laminates were started. An analysis was made of the matrix configuration and requirements for the electrostrictive switch in the ELF application.

250. Westinghouse Electric Corp., Baltimore, Md. ELECTROLUMINESCENT FERROELECTRIC (ELF) SOLID STATE DISPLAY. Quarterly interim development rept. no. 16 for 1 Mar–31 May 1962. 31 May 1962. 6p. (Contract NObsr-72782) ASTIA AD 277-755.

251. Westinghouse Electric Corp., Baltimore, Md. ELECTROLUMINESCENT-PHOTORESPONSIVE COMPUTER ELEMENT RESEARCH. Final rept. Westinghouse rept. no. 4505. 31 Aug 1960. 85p. [Contract AF 33(616)6304, Proj. 7062) (WADD TR 60-863) ASTIA AD 259-395.

Research was concerned with the development of an electroluminescent-photoresponsive (EL-PR) computer element. The objective was the development of a computer element with microsecond switching speed, an impedance ratio of 50 to 1 off to on, and a power gain greater than unity. Existing electroluminescent and photoconductive devices and materials, as well as anticipated improved versions of these devices and materials were analyzed. These investigations show that either the microsecond switching speed and the 50 to 1 impedance ratio or the power gain greater than unity and 50 to 1 impedance ratio could be realized with existing materials. However, the achievement of all three objectives in the simple EL-PC (Photoconductive) device will require a major breakthrough either in the form of EL materials with greater efficiency of a PC device with inherent gain.

252. Westinghouse Electric Corporation IMPROVED RED ELECTROLUMINESCENT PHOSPHORS. Final Report. Dec 1961. 128p. AFSC Project 7360, Task 73614. [Contract AF 33(616)7350] ASTIA AD 272-786.

A large number of materials of potential interest as red-emitting electroluminescent phosphors have been studied experimentally. The following new red emitters were investigated in some detail: ZnS:Cu, Li, Ti, ZnS:Cu, Fe, I, and hexagonal (Zn, Cd)S: Cu, I. $ZnAl_2S_4$ was also shown to be of some interest as a new base material for

phosphor preparation. The best red electroluminescent phosphor is still cubic (Zn, Cd, Hg)S:Cu. With improved techniques of lamp construction a brightness of 1.0 ft-L at 115 volts, 400 cps can be achieved with such a phosphor having "Aviation Red" color. The maintenance of output of red phosphors is a major problem; the best material shows only 50% of its initial output after about 15 hours of operation at 400 cps.

253. Wilburn, D. K.
Industrial fluoroscopic inspection by electro-luminescent x-ray converters. ELECTRONICS 34:56-58, 15 Sep 1961.

Electroluminescent X-ray converters which give higher brightness than conventional fluorescent screens are described. Brightness is increased by several orders of magnitude, together with improved resolution and contrast, at operating energies in the 150 to 500 Kvp X-ray range. Physical construction of the basic converter is given including a schematic of the converter and its power supply, using interdigitated electrodes for erasing latent images. In the electroluminescent X-ray intensifier, a stratum of photoconductive CdS is sandwiched between the e-1 layer and the top electrode, while an opaque film over the e-1 layer eliminates excitation from visible light. Photo-conductive material is non-conducting in the dark but conducts when exposed to X-rays. When conducting, the photoconductor applies a voltage to the e-1 layer, which in turn emits visible light. Another important property of the photoconductor is its ability to absorb X-ray photons. The converters are useful in medical therapy; in industry they can be used as radio-graphic penetrameters, for examination of hermetically sealed devices and in other forms of non-destructive testing.

254. Wilburn, D. K.
A SOLID STATE ELECTROLUMINESCENT X-RAY INTENSIFIER. Ordnance Tank-Automotive Command, Detroit, Mich. Rept. no. RR-35. 1 Mar 1961. 48p. ASTIA AD 266-800.

A new solid state high resolution x-ray panel amplifier is described, and evaluated under practical operating conditions. Data on contrast and detail sensitivity is presented and comparisons are made with conventional radiographic fluorescent screens. Intensifier output brightness is discussed as a function of x-ray excitation for energies up to 15 MEV. Typical panel amplifiers were viewed remotely with a high resolution low light level image orthicon system employing electronic storage techniques. For x-ray energies below 300 KVP, electroluminescent panels were viewed directly through 6-inches of lead glass. Kinescope photographs are presented to illustrate performance characteristics at higher x-ray energies. Procedures and techniques for remote

viewing of fluorographic images are discussed, and recommendations made relative to achieving optimum performance.

255. Williams, F. E.
Irreversible thermodynamics of injection electroluminescence. BULL. AM. PHYS. SOC. SER 11 5:70, 27 Jan 1960.

The possible generation by minority carrier injection of electroluminescent emission exceeding the electrical input was discussed. The additional energy would be taken as heat from the lattice and the system would thereby cool. Equilibrium thermodynamics has been applied to the problem and tends to support the possibility. Injection electroluminescence can readily be shown to be irreversible. The application of irreversible thermodynamics provides more severe limitations on the efficiency of injection electroluminescence. Because the second law must be satisfied locally for irreversible processes the entropy increase associated with the radiation must at least balance the entropy decrease accompanying electron-hole pair annihilation. This requirement precludes quite generally realistic electroluminescent emission intensities in excess of the electrical input. Radiative recombination at impurities introduces additional limitations. The thermodynamic limitations which are common to both electro- and photoluminescence were discussed.

256. Windebank, R. W.
Electroluminescent display presents nanosecond pulses. ELECTRONICS 34:53–55, 8 Dec 1961.

A flat-screen electroluminescent display which shows short-duration pulses of nanosec. width is described. The display is produced by coincidence of oppositely travelling pulses. When the pulses meet, the voltages add to illuminate the electroluminescent element at that point. By connecting a tapped delay line to panel electrodes, the length of a pulse can be determined by measuring the length of the resultant visual display. An experimental model with 50 discrete phosphor sections, with synchronized pulses applied to both ends, illuminated one section for each 10 nanosec of applied pulse width. A video signal can be displayed by applying the video to one end of a delay line and a single exploring pulse to the other. The pulse coincides in turn with the separate elements of the video waveform, providing the display.

257. Winkler, H. and H. Roppischer
On the intensification of the luminescence
by electric fields of zinc cadmium sulphides
activated by manganese. WISS. Z. HOCHSCH.
ELEKTROTECH. ILMENAU 6:113–117, 1960.
(In German)

Intensification of luminescence under the influence of alternating electric fields was observed in zinc cadmium sulphide activated by manganese and excited by X-rays. Intensification factors from 4 to 7 were measured in the yellow emission range. No field extinction was observed between the wavelengths of 430 and 700 mm. The intensification is voltage and frequency dependent and it is thus assumed that no radiation controlled luminescence has occurred. The material has shown memory effects even in the case of presensitivation by electric field only.

258. Winn, J. B.
STUDY OF SOLID STATE MATRICES FOR USE
IN DATA PRESENTATION AND DISPLAY.
White Sands Missile Range. Range Instrumentation
Development Div., N. Mex. Final Report.
NASA Rept. no. N62-13654. 1 May 1962. 58p.

The fundamental principles of electroluminescent and electroflor devices are described, together with construction details and applications of selected devices, some of which are commercially available. The devices studied or tested include: a rayescent readout lamp, which displays data in alpha-numeric form; a panelescent lamp, also available as an alpha-numeric display; a mobile dot sylvatron, which converts electrical data into momentary dots of light at any desired location on the panel; a mosaic sylvatron, which displays and stores information; an image converter, which reproduces, as electroluminescent images, patterns or pictures which are projected on the back surface of the device; an RCA solid state light amplifier, which produces an output pattern or picture with a gain of at least 40 when a light image is incident on the back surface or photconductive layer; an electrflor pane, which converts electrical data into light by means of electrochemical color changes; and a three-dimensional electroflor display.

Possible application, such as "and" gating, "or" gating, data translation, binary-to-decimal conversion, decimal-to-binary conversion data storage, data display, aircraft control, and permanent record photography, are discussed. Tests which were made and equipment which was developed are briefly discussed.

259. Yamashita, H., et al.
Electroluminescence of CdS single crystal.
J. PHYS. SOC. JAPAN 15:2366, Dec 1960.

Electroluminescence emission observed in very pure high resistance CdS single crystals near the anode is discussed. Yellow, green, and orange spots were initially observed. When the current exceeded a few hundredths of a microampere green "curtains" about one mm long were observed. The curtains expanded and contracted as they were observed and were found to consist of many stripes perpendicular to the field. The green emission had a very narrow band at about 5300A and the orange emission had a broad band with the maximum at about 6000A. It is believed that the yellow emission is due to mixing of the green and orange emissions. Luminescence measurements as a function of temperature indicate that the emission is caused by a bimolecular mechanism.

260. Yando, S.
Solid-state display device. IRE INTL. CONV.
REC. 9(Part 3):45–52, Mar 1961.

A solid-state display device consisting of a thin, flat panel of piezoelectric material, one surface of which supports an electroluminescent layer is described. Voltage pulses, applied to several electrodes suitably positioned on the periphery of the panel, introduce traveling acoustical waves into the piezoelectric material. Electric fields accompany the waves so produced and interact with the electroluminescent layer to produce a localized "spot" of illumination. The position of the "spot" is controlled by varying the relative timing of the pulses to produce either a raster or an oscilloscope pattern. Means for continuously modulating the light intensity of the "spot" are also described.

261. Yando, S.
ELECTROLUMINESCENT DEVICES. (Assigned
to Sylvania) U.S. Patent 2,922,923. 26 Jan 1960.

An electroluminescent device for observing the interaction between three pulses is described. One pulse train is applied to a pair of electrodes on the opposite faces of one end of a piezoelectric strip, and a second pulse train is applied to a pair of contacts on opposite faces at the other end of the strip. A third pulse train is applied between an electrode on one surface of the piezoelectric strip, between the end contacts, and a transparent electrode of the same surface area applied to an electroluminescent layer on the other surface of the piezoelectric strip. The electric fields associated with the elastic waves produced by the first two pulse trains and the electric

field of the third pulse train produce a spot of light on the electroluminescent layer. The position of the spot depends on the relative timing of the pulses. By continuously varying the relative timing, the spot of light will scan the strip at a velocity dependent on the rate of timing variation. The light intensity of the spot can be modulated by varying the pulse amplitude.

262. Zallen, R., W. T. Eriksen, and H. Ahlburg
Electroluminescence under pulsed square wave excitation. J. ELECTROCHEM. SOC. 107:288–295, Apr 1960.

The slow return of electroluminescent cell to its equilibrium state following a field excitation has been studied for a blue-green emitting Zn(S,O):Cu, Cl phosphor and for a yellow-emitting ZnS:Mn, Cu phosphor. The light pulse emitted upon the rise of a square voltage pulse was measured as a function of repetition rate and of temperature between -130° and 150°C. Relaxation times encountered varied between 10^{-2} sec and 10^{5} sec. The temperature dependence of the relaxation rate exhibits effective activation energies of about 0.4, 0.7 and 0.6 ev, respectively, for the blue, green and yellow emission bands. The results do not seem to favor the mechanism of delayed recombination. An alternative mechanism is suggested whereby the number of filled deep donors is assumed to control the electroluminescence emission via the number of field-ionizable electrons available for collision-excitation of centers. Observations were also made on some other effects associated with square wave excitation.

262A. Zalm, P., et al.
ELECTROLUMINESCENT MATERIALS.
(Assigned to N. V. Philips) German patent 1,097,597. Class 22f. Applied 1 Feb 1954. (in the Netherlands, 4 Feb 1953) (In German)

EL materials are produced by a mixture which is heated at 800–1200° in a hydrogen sulfide atmosphere or in an atmosphere of carbon disulfide and nitrogen.

263. Ziegler, C. A., et al.

Electroluminescent pressure gauge. REV. SCI. INSTRUM 33:812–818, Aug 1962.

This report describes work undertaken to design and build a pressure gauge utilizing a unique pick-off which couples the phenomena of electroluminescence and photoconductivity to obtain a completely solid-state device having a low impedance output capable of detecting very small mechanical displacements (microinches) of bellows and diaphragm pressure sensors. Advantages of this device as applied to pressure measurement are small size and weight, very high resistance to shock and vibration, and continuous resolution over a wide dynamic range. A prototype pressure gauge capable of measuring pressures from 0 to 800 mm Hg and having an electrical output of 1 to 5 V when operated from a 28 V d.c. power source is described.

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